Critical habitat features of giant kokopu, *Galaxias argenteus* (Gmelin 1789).

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ABSTRACT

The giant kokopu (*Galaxias argenteus*) is the largest of the galaxiid fishes, and is endemic to New Zealand. Some landlocked (non-migratory) populations exist, but giant kokopu are normally diadromous, and juveniles make up a small part of the annual whitebait run. The species is now regarded as threatened, and its rarity has led to controversy over proposed changes to whitebait fishing regulations. Although exploitation of the juveniles may be limiting recruitment to adult populations, the perceived decline of giant kokopu has been attributed mostly to the loss and degradation of its habitat. In order to manage and conserve the species, the critical features of giant kokopu habitat need to be determined.

Analysis of information from the New Zealand Freshwater Fisheries database, and from field surveys in Southland and along the western coast of the South Island, indicate that five habitat features are critical: the presence of instream cover, deep water, low water velocity, proximity to the sea, and overhead shade/riparian cover. These features were critical in both regions surveyed and for both juvenile and adult fish. The effects of different types of riparian and instream cover were examined, but it appeared that the presence of some sort of cover was more important than its composition. Giant kokopu readily utilised artificially constructed habitat, which emphasised the importance of instream cover and low water velocity.

Diet was investigated from the examination of the gut contents of 105 fish, and results compared to other published information. Giant kokopu are probably best described as opportunistic feeders, as they utilise a wide range of foods of both aquatic and terrestrial origin. Terrestrial components of the diet appear to be significant for giant kokopu, which may partly explain the importance of overhead shade and riparian cover in giant kokopu habitat.

Giant kokopu have been found in a wide variety of water types around New Zealand, and are known to co-occur with 33 other native and introduced species of fish. It appears that they are more likely to occur in habitats where introduced

brown trout (*Salmo trutta*) are absent, although the two species do sometimes co-occur and can not be said to be mutually exclusive.

Migrations of juvenile (whitebait) giant kokopu into freshwater probably occur mostly after the end of the whitebaiting season, and their capture may no longer be a serious conservation concern. The impact of commercial eel fishing on giant kokopu populations is difficult to determine, and there may well be both detrimental and beneficial effects.

The conservation and management of giant kokopu will probably continue to be based upon management of their habitat, and these processes will be enhanced by the knowledge of the species' habitat requirements.

1. INTRODUCTION

The giant kokopu (*Galaxias argenteus*) is the largest species of the galaxiid fishes, and is endemic to New Zealand. Although landlocked (non-migratory) populations exist in some lakes and ponds (McDowall 1990), it is one of five diadromous species of *Galaxias* that have a marine phase, with juveniles (known as whitebait) that migrate into rivers in mixed-species shoals during the spring (McDowall and Eldon 1980). Although widespread, this species is uncommon, and is regarded as threatened (Williams and Given 1981; Tisdall 1994). In many parts of New Zealand the giant kokopu is perceived as being rare, especially in eastern areas, and particularly where there are large human populations or where land is developed for agriculture. This decline has coincided with extensive land development, wetland drainage, and stream realignment in many parts of New Zealand, and McDowall (1990) suggests that as pastoral development continues, it is likely that the decline of the species will continue.

Because there are serious concerns about the conservation status of giant kokopu, ways of ensuring its long-term protection are being sought. Without knowledge of its habitat requirements, it would be difficult to protect the species and make rational decisions about impending land use changes or the establishment of reserves. One of the most effective contributions to ensuring its protection is to obtain an understanding of the critical features of habitats favoured by the species. This information can form a basis for the development and application of viable strategies for managing populations and habitats, and for ensuring the protection of the species.

1.1 Historical and biological background

The giant kokopu was the first galaxiid to be scientifically described, being collected by naturalists visiting New Zealand with Captain James Cook in 1773 (Forster 1844). It was initially known as *Esox alepidotus* (the scaleless pike) probably because of superficial similarities with the Northern Hemisphere pike, such as the large, well-toothed mouth and the dorsal fin set well back on the trunk. The formal description by J.F. Gmelin (1789) as *Esox argenteus* is puzzling, as *argenteus* means "silvery", whereas giant kokopu is a dark olive or brown fish with distinctive gold spots (Fig. 1). George Cuvier, a French biologist, was the first to recognise that the fish was not a pike, and named it *Galaxias* because its spotted colour pattern resembled a galaxy of stars (Cuvier 1812). The international rules governing zoological nomenclature preclude changing Gmelin's older but inappropriate "*argenteus*", and the species is today known as *Galaxias argenteus*. Other common names include Maori trout, bull trout and native trout.

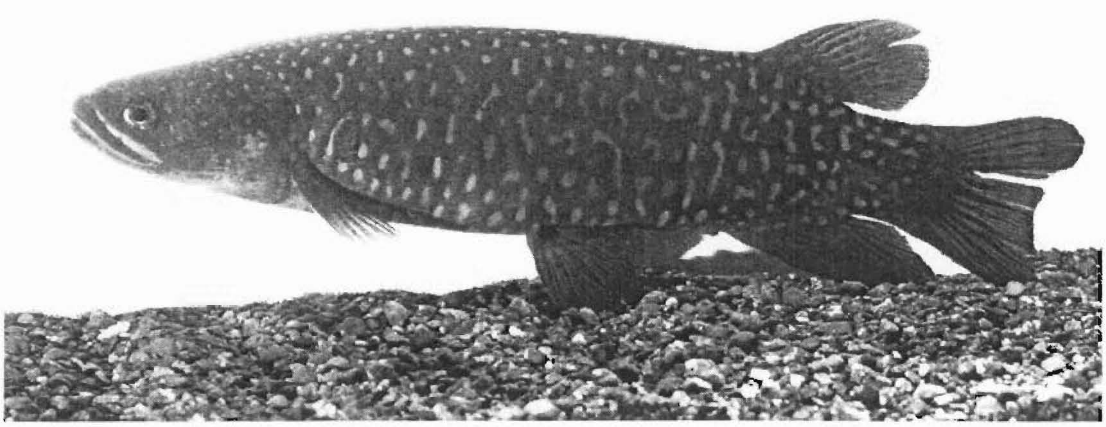

Figure 1. An adult giant kokopu (*Galaxias argenteus*), fork length approximately 270mm. (Photograph R.M. McDowall)

The giant kokopu is widely mentioned in both Maori and early colonial literature (McDowall 1990). The fish was certainly encountered by gold miners working in the streams and swamps of Westland during the 1860s, and was also quite widely known to early explorers and settlers, such as Charles Heaphy and Charles Douglas (Heaphy 1842; McDowall 1980).

Current information on the biology and distribution of giant kokopu is limited and fragmented. Since 1979 there has been some information published on their diet, age and growth (Jellyman 1979; Main 1988), and more recently on the date of and age at migration of giant kokopu whitebait (McDowall and Kelly 1999). Taylor (1988) summarised information on giant kokopu habitat preferences derived from a broad survey of fish populations in rivers of South Westland (Taylor and Main 1987).

Adult giant kokopu may exceed 400 mm in length and weigh more than a kilogram, but generally a "large" giant kokopu would be anything over 300 mm and/or 500 g. Large fish are more likely to be females (Rasmussen 1990), as is the case for females of *G. fasciatus* (Hopkins 1979), *G. maculatus* (McDowall 1968a), *G. eldoni* and *G. anomalus* (Allibone and Townsend 1997).

It comes as a surprise to many people that the giant kokopu is one of the whitebait species, because the adult bears little resemblance to the slim, transparent juvenile. Giant kokopu whitebait are a minor component of the annual whitebait catch and appear in very small numbers in catches towards the end of spring (McDowall 1990; McDowall and Kelly 1999). Presently, the annual whitebait fishing season finishes in mid- to late November, whereas giant kokopu whitebait mostly appear in the catches from early November onwards (McDowall and Eldon 1980; McDowall and Kelly 1999). Clearly, the longer the season the greater the potential risk to giant kokopu recruitment. Conversely, an earlier end to the fishing season may offer giant kokopu protection from exploitation in the fishery. Moves to change the season and offer such protection created controversy over the regulations, culminating in a review of proposed regulatory changes by the Regulations Review Committee of Parliament (New Zealand House of Representatives, 1994).

The giant kokopu probably takes three years to reach maturity (Rasmussen 1990), and may live for many years; a large adult fish (400 mm long and weighing 1.05kg) was estimated from otolith growth rings to be between 21 and 27 years old (McDowall 1990). After the first two or three years, growth is slow; Jellyman (1979) found that it varied from 1.9 to 13.4 mm per year at lengths between 234 and 330 mm. Giant kokopu whitebait are mostly 45-50 mm long and almost totally unpigmented apart from the musculature being a pale amber (McDowall and Eldon 1980). After entering fresh water they gradually develop a dull greenish-grey colouration with a silvery-olive belly. Then up to six or eight pale vertical bands or blotches develop on the sides, and the fish becomes quite stocky. Because of the bands, juvenile giant kokopu are hard to distinguish from banded kokopu (*G. fasciatus*). As the fish grows, banding and blotching fade beneath the distinctive adult colour markings.

Spawning habitat has not been described, although there have been several observations of downstream movements of significant numbers of ripe adult male giant kokopu during late autumn and early winter (McDowall 1990). In a landlocked population in Southland, spawning appeared to be mostly complete by the end of June, although the wide size range of juveniles caught in December suggests that spawning may take place over a considerable length of time (Rasmussen 1990). Recent research on the date and age at migration of giant kokopu whitebait indicates that spawning occurs between early June and early August (McDowall and Kelly 1999). Eggs in ripe females are relatively small, about 2 mm in diameter, and a female 336 mm long contained 25 000 eggs (Jellyman 1979).

Some studies suggest that giant kokopu feed predominantly on terrestrial insects (Jellyman 1979; Main et al. 1985), although Main and Lyon (1988) noted giant kokopu feeding on insects in stream drift, and Main (1988) found that aquatic prey formed 87.9% of prey items by abundance. The diet of landlocked adult fish included a wide range of prey items, including juvenile giant kokopu (Rasmussen 1990). It would appear that giant kokopu are opportunistic feeders, and McDowall (1990) suggests that the shape and position of its fins adapt it for behaviour as a "skulking predator".

1.2 Objectives, aims and approaches

The primary objective of this study was to determine the habitat requirements of giant kokopu, and identify which features (if any) were critical. In this study "critical features" are defined as those that distinguish between suitable and unsuitable habitat for giant kokopu; in other words giant kokopu will normally be present only in areas that contain the identified critical features. The term "critical" is not intended to imply that a feature is vital, and none of the features surveyed could be said to be vital for giant kokopu (probably the only vital feature of giant kokopu habitat is the presence of water).

The presence of any single "critical habitat" will not necessarily ensure the presence of giant kokopu, as a number of features may be critical. For instance, if both water depth and overhead shade were found to be critical for giant kokopu, it implies that deep water with overhead shade is suitable habitat. However, deep water without shade, or shallow water with shade, may provide much less suitable, or even unsuitable, habitat.

It may be that any critical habitat features are strongly, but indirectly, associated with the occurrence of giant kokopu. For instance, riparian vegetation might be shown to be a "critical feature". This may be an indirect association, as its presence may enhance terrestrial food sources for giant kokopu. If other sources of food are available to the fish, the presence of riparian vegetation may be irrelevant.

The importance of habitat may be closely linked to the food sources it provides, and the analysis of giant kokopu gut contents may provide some insights to the links between habitat and diet.

To achieve the objective, the following aims were established:

1. To locate populations of giant kokopu suitable for detailed habitat surveys.
2. To determine the distribution of giant kokopu with respect to general habitat features such as altitude and inland penetration.
3. To identify broad habitat preferences, such as water type (stream, lagoon, lake, swamp).
4. To determine the co-occurrence of giant kokopu with other species of native and introduced fish.
5. To survey a range of habitats and measure features where giant kokopu were caught or seen.
6. To develop a multivariate model using survey data to identify critical features.
7. To use information from the model to determine if the same identified critical features occur in different geographical locations and/or at different life stages.
8. To capture and tag juvenile giant kokopu in a stream, and determine if their distribution in the catchment alters significantly as they grow.
9. To observe experimental structures in a stream, and determine if giant kokopu utilise them.
10. To observe catch-per-unit-effort along a lakeshore to determine if giant kokopu show preference for vegetated or non-vegetated shores.
11. To examine gut contents of preserved giant kokopu to determine the relative importance of terrestrial and aquatic food items.

Four separate approaches were used in pursuit of the above aims, and each of the following four sections details the approach, the methods used, and the results based on each aim. Briefly, the approaches were:

1. The retrieval of information on the distribution and broad-scale habitat use of freshwater fish from the New Zealand Freshwater Fisheries Database (NZFFD). This provided general information from diverse sources. (Aims 1-4).
2. Surveys of habitat utilised by giant kokopu in the Southern and Western regions of the South Island, New Zealand, and multivariate analysis of the data to provide a model of habitat selection. The main purpose of the model was to determine which features of giant kokopu habitat (if any) were critical. (Aims 5-7)
3. Observation of experimental structures in a stream, and of catch per unit effort in a lake, and comparing the results with hypotheses on the use of cover. (Aims 9 & 10)
4. Analysis of gut contents, particularly the relative importance of terrestrial versus aquatic food sources. (Aim 11)

Only aim 8, to locate a suitable stream for tagging juvenile giant kokopu, was not achieved. The hypothesis was that in a small coastal stream juvenile fish move upstream of the reaches occupied by adult fish, but drop downstream as they grow. Juvenile fish (approximately <120mm) were each to be marked with an individual visible implant tag (VIT) and hopefully recaptured somewhere within the same stream at a later date. I was unable to locate a suitable stream with sufficient numbers of juvenile fish to tag. Those juveniles that were encountered appeared to be distributed in much the same pattern as adults, and adult and juvenile fish were caught in close proximity.

Visual implant tagging was found to be unsuitable for giant kokopu in any case. The method relies on a small numbered tag remaining visible and readable after insertion under the skin of the fish, but giant kokopu are heavily pigmented and there was no obvious "clear" location suitable for inserting a tag on a small fish. Before attempting visual-implant tagging in the field, I practiced on a dead giant kokopu from the collection of the National Institute of Water and Atmospheric Research (NIWA). This was a large specimen (approx 370mm), but the only place suitable for implant tagging was in a fold of clear skin near the hinge of the jaw, and unfortunately in juvenile fish this area was too small to allow tagging.

A further complication was the difficulty I had with distinguishing juvenile giant kokopu from banded kokopu *(G. fasciatus)*. Fish of these two species are very similar at lengths up to approximately 150mm; they have almost identical body shapes and vertical bands of colouration along the sides. The subtle differences between the species are not easily recognised using live specimens, especially when viewed in poor light. As they grow, giant kokopu develop distinct and unique colouration patterns, and identification is straightforward.

2. DISTRIBUTION AND BROAD-SCALE HABITAT PREFERENCES FROM THE NEW ZEALAND FRESHWATER FISHERIES DATABASE

The New Zealand Freshwater Fish database is an historic archive of information on the distribution of New Zealand freshwater fishes, containing data principally from the last 30-40 years (McDowall and Richardson 1983; Richardson 1989). The database is managed by NIWA, which has responsibility for data entry, quality control, storage, and retrieval. Data have been contributed by a diverse range of individuals and organisations, including government departments, crown research institutes, research agencies, fish and game councils, universities, and recreational and commercial fishers. Many records contain only basic data (date, location and map reference, presence of fish species), whereas some records have more detailed information on the abundance of fish species and the habitats where they were found. The methods and objectives of the various contributors have varied widely, however the data still provide a heterogeneous and valuable collection of information on New Zealand's freshwater fish fauna.

Records from the NZFFD were copied onto a personal computer and analysed using spreadsheets and the statistical analysis software SYSTAT 8.0 (Wilkinson 1998). The database was used initially to identify areas where giant kokopu were most common and which would be suitable for more intensive study. Database information was also used to construct a distribution map and to examine giant kokopu occurrence and habitat selection with respect to broad habitat features such as elevation, distance inland, and water type. Information on many of the database records also provided some measure of abundance, length frequency and co-occurrence with other native and introduced fish species.

The analyses were conducted in June 1999, when there were 14 343 records in the NZFFD, with each record representing information from one site. Of these, 665 were "null" records (i.e., records from locations where no fish were caught) and 561 were records of sites containing giant kokopu. Thus giant kokopu have been found in approximately 4% of the sites sampled around New Zealand. These fish were recorded from 154 distinct catchments (as defined in "Catchments of New Zealand", Soil Conservation and Rivers Control Council, 1956). An unknown number of records were "repeats" from the same sites at different times, or from localities in very close proximity. Comparisons made in this study were based on the assumption that duplication was unlikely to seriously distort the analyses. Chi-squared tests were used, where appropriate, to test the significance of comparisons between giant kokopu sites and all the sites containing fish. Statistical analysis of NZFFD records must be viewed with caution, however, as the records may be biased; at any one site some species may have a vastly different probability of capture, and may therefore be misrepresented on the database. Moreover, the database may be dominated by records from accessible sites that are easy to sample, which may present a skewed picture of fish abundance and distribution. Nevertheless, basic statistical analysis does allow patterns and trends in the data to be identified.

2.1 Identifying regions for habitat surveys

Data from the NZFFD were used to create a map of the distribution of giant kokopu (Fig. 2). It was immediately obvious from the map that giant kokopu were more frequently encountered along the west coast of the South Island ("Westland") than anywhere else; of the 561 records, 312 (56%) were from this region, including some from relatively unmodified forest catchments. There were also 67 records (12% of the national total) from the south of the South Island ("Southland"), many of which were from modified streams and drains in a pastoral/agricultural environment. Clearly these two regions were suitable for habitat surveys, and also provided the opportunity for some useful comparisons between habitats in developed areas of Southland and the less disturbed and more forested waters of Westland.

2.2 Distribution

The locations of site records on the NZFFD are stored on the basis of map grid references and catchment definitions, and not by generalised region or province. For clarity, in this study I have assigned 12 generalised regions in the North and South Islands as presented in Fig. 3.

Giant kokopu are widely distributed throughout much of New Zealand, and are known to occur on the three main islands, on Great and Little Barrier Islands, and in the Chatham Islands (Skrzynski 1967; Rutledge 1992). However, they are far from being evenly distributed. They are uncommon along the east coast from East Cape to Otago, and absent from most of Northland (Fig. 2). Nearly all the records (87%) on the NZFFD are from only four generalised regions: Westland, Wellington, Southland, and Waikato. All the other records (from areas including Otago, Taranaki, Bay of Plenty, and Auckland) make up only 13% of the total. To some extent the uneven distribution of giant kokopu is exaggerated by sampling effort, and it must be noted that Westland, Wellington, and Waikato have been extensively studied (McDowall 1990). However, in other heavily sampled regions, such as Taranaki and Canterbury, giant kokopu have been infrequently recorded. The sparseness of giant kokopu in eastern areas parallels that of three other diadromous galaxiid species; banded kokopu (*G. fasciatus*), shortjawed kokopu (*G. postvectis*) and koaro (*G. brevipinnis*). In fact, of all the whitebait species, only inanga (*G. maculatus*) comes close to being uniformly distributed around the country (McDowall 1990).

It seems likely that the sparseness of giant kokopu in some areas can be attributed largely to a lack of suitable or available habitat, rather than some other, more general, factor that excludes the fish. Much of this habitat shortage can be attributed to wetland drainage, land development, stream realignment and draglining. Probably less than 10% of New Zealand's wetlands remain (Anon. 1983). In Canterbury, for instance, vast areas of wetland have been drained, around Lake Ellesmere, and along the coastal strip from the Ashburton River to the Waitaki River (McDowall 1998). Wetlands in Canterbury are now very

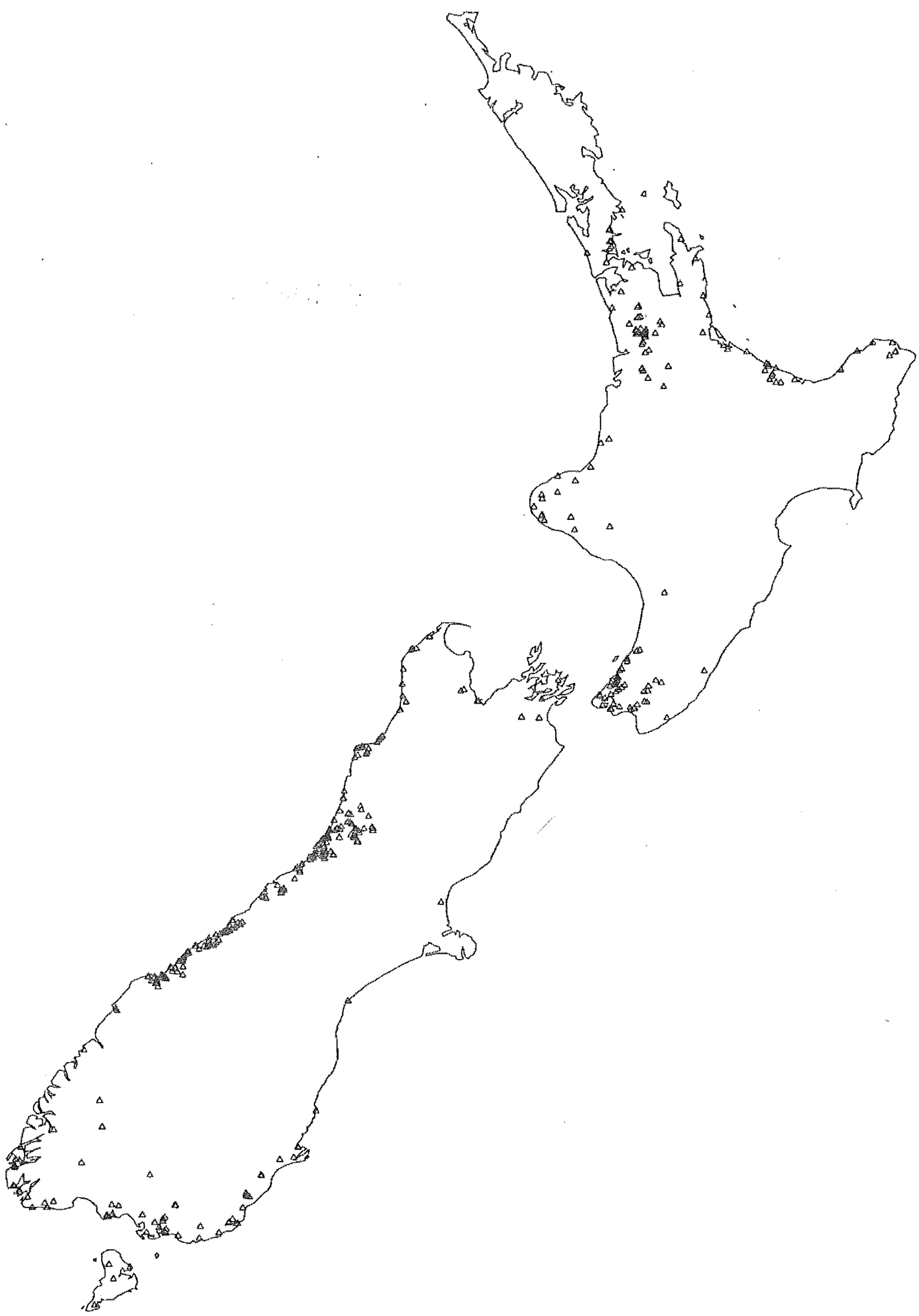

Figure 2. Distribution of giant kokopu (*Galaxias argenteus*) around New Zealand. NZFFD sites containing giant kokopu are represented by small triangular symbols. Chatham Islands sites are not shown.

Figure 3. General regions of New Zealand, and place names mentioned in the text.

sparse, and apart from a landlocked population of giant kokopu known to occur in Horseshoe Lagoon, near Temuka, there are only two definite records of giant kokopu from Canterbury in the past 50 years. Yet in the mid-1800s, the fish was well known from at least some of the South Canterbury wetlands and associated streams (Studholme 1940), and it was certainly recorded from the vicinity of Lake Ellesmere (Stokell 1949). The Waikato had lost 50 000 ha of wetland by the late 1970s (Thompson 1979), and although giant kokopu remain relatively widespread in the Waikato catchment (Fig. 2), there can be little doubt that numbers are greatly diminished there (McDowall 1990).

2.3 Abundance

At each of 561 sites where giant kokopu were recorded, some measure of their abundance was also noted. In many instances this was a relative measure (terms such as "rare", "common" etc.), but in some cases actual numbers of fish caught were recorded. Of these, just over half (51%) specified a single specimen, and 6% specified more than 10 specimens (Fig. 4).

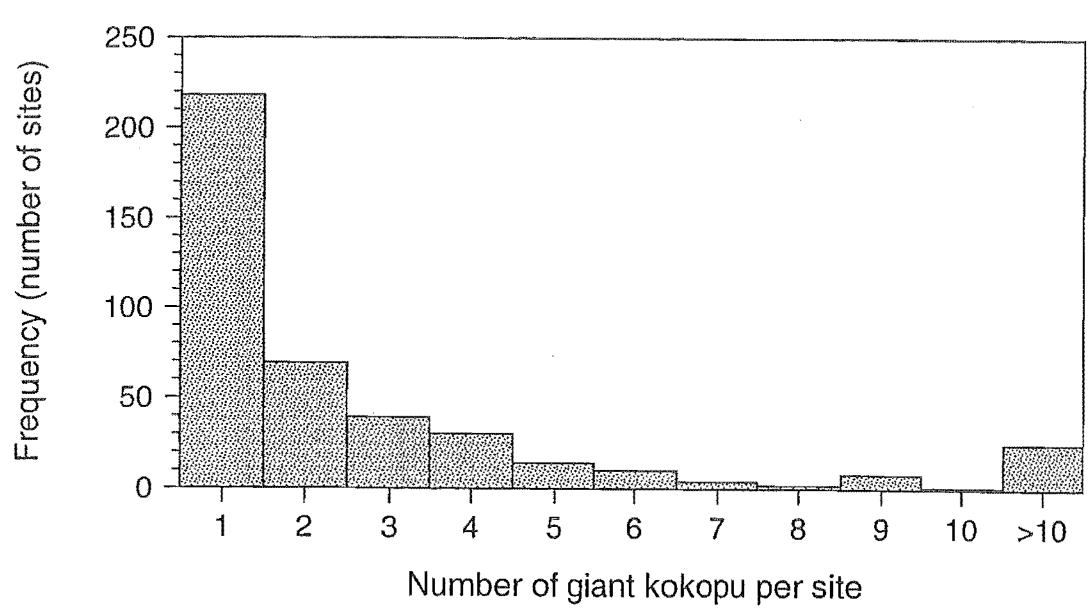

Figure 4. Abundance of giant kokopu recorded at NZFFD sites.

It is interesting to note the relatively high proportion of sites with >10 specimens. This figure is partly influenced by the inclusion of records for juvenile giant kokopu caught in whitebait nets. However, records for catches of 10 or more adults are not uncommon, and in one site 174 adult giant kokopu were recorded. Many of these records were contributed by commercial eel fishers using fyke nets, in which giant kokopu are readily caught, but there are also some such records for electrofishing. In fact giant kokopu have been caught or observed using a variety of methods: of the 561 records, 196 (35%) were for electrofishing, 162 (29%) for fyke netting, 116 (21%) for other nets and traps, and 87 (15%) for other, unknown or unspecified methods. The latter include six records where angling was used, one using diving (a giant kokopu was found dead on the streambed), and 38 instances of fish being recorded by observation.

Despite 51% of the records being of single specimens, abundance data from the NZFFD imply that, where giant kokopu occur, they are often present in significant numbers, i.e. as a population.

2.4 Size

The giant kokopu has historically been recorded up to 580 mm in length and weighing 2.7 kg (Clarke 1899), but modern data suggest that this was an exceptionally large specimen. NZFFD data include 114 records of length of giant kokopu, for which a length/frequency plot is presented in Fig. 5a. Length data were also collected during the field surveys for the present study in Westland and Southland, and these are presented for comparison in Fig. 5b. For most fish species it would be expected that juvenile fish would dominate, so the proportion of "large" giant kokopu in the samples is notable. There are several possible reasons for this. Firstly, juvenile fish may be less frequently encountered because they are small and cryptic. Secondly, small fish are more difficult to see and catch either by electrofishing or in fyke nets. Thirdly, juveniles may be most common in different (and difficult to sample) habitat types, either by choice, or because they are excluded from adult habitats by competition or predation. Fourthly, it is likely that some juvenile giant kokopu are not recorded as such, because they have been mis-identified as banded kokopu.

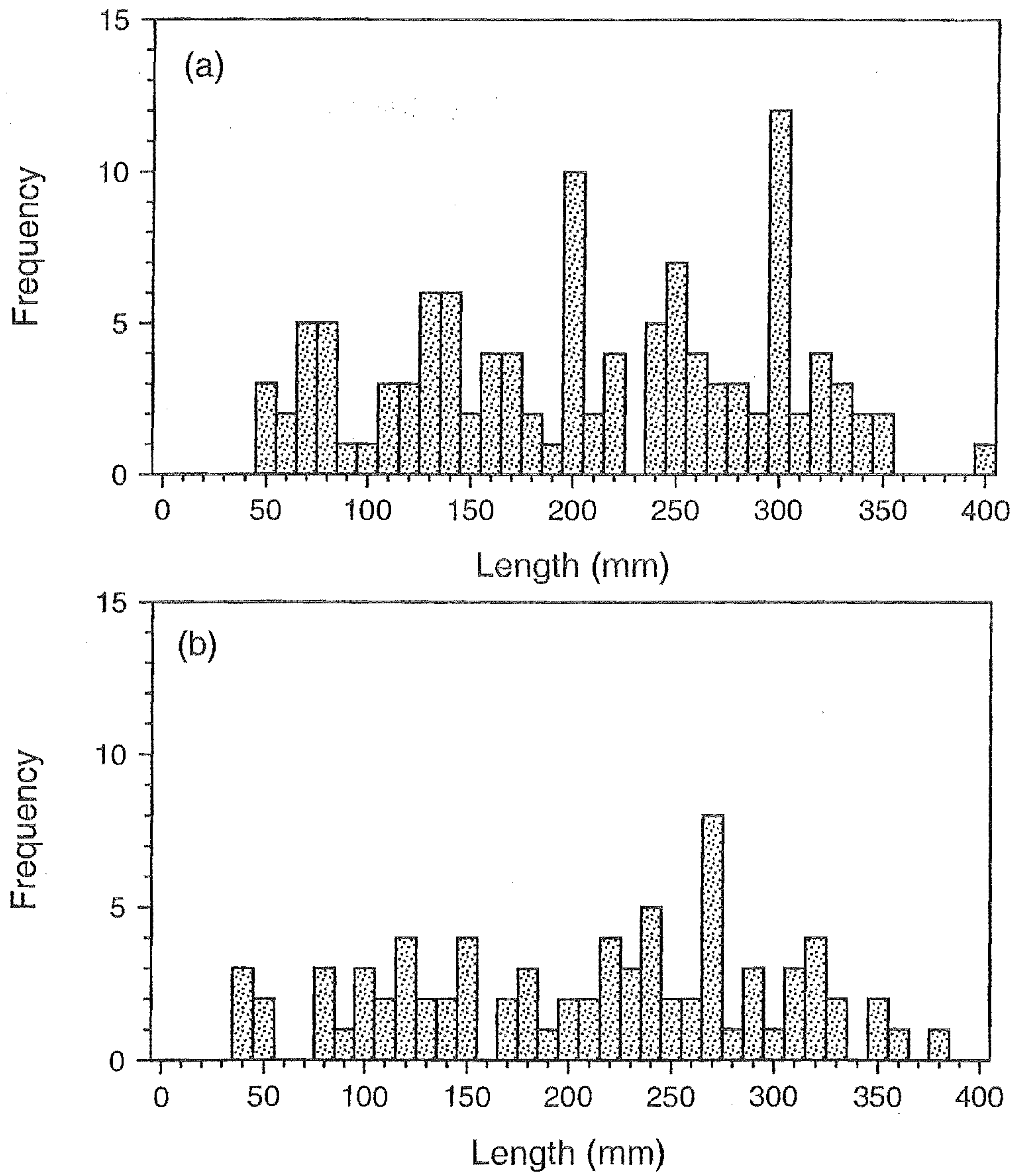

Figure 5. Length frequency of giant kokopu recorded on (a) the NZFFD (N=114), and (b) from surveys in Westland and Southland (N=78).

Length records from the NZFFD have "peaks" at 200, 250 and 300 mm (Fig. 5a), but these are probably artefacts corresponding to estimated rather than measured length, and are not indicative of age classes. Length and weight measurements for 40 fish from field surveys in Westland and Southland in autumn 1999 were also used to calculate a length/weight relationship for fish from 44 to 380 mm in length:

$$W = 5.0912 \times 10^{-6} L^{3.1774} \text{ (n=40, } r^2\text{=0.992)}$$

Where W = wet weight (in grams) and L = fork length (in millimetres). The relationship is also presented in Fig. 6.

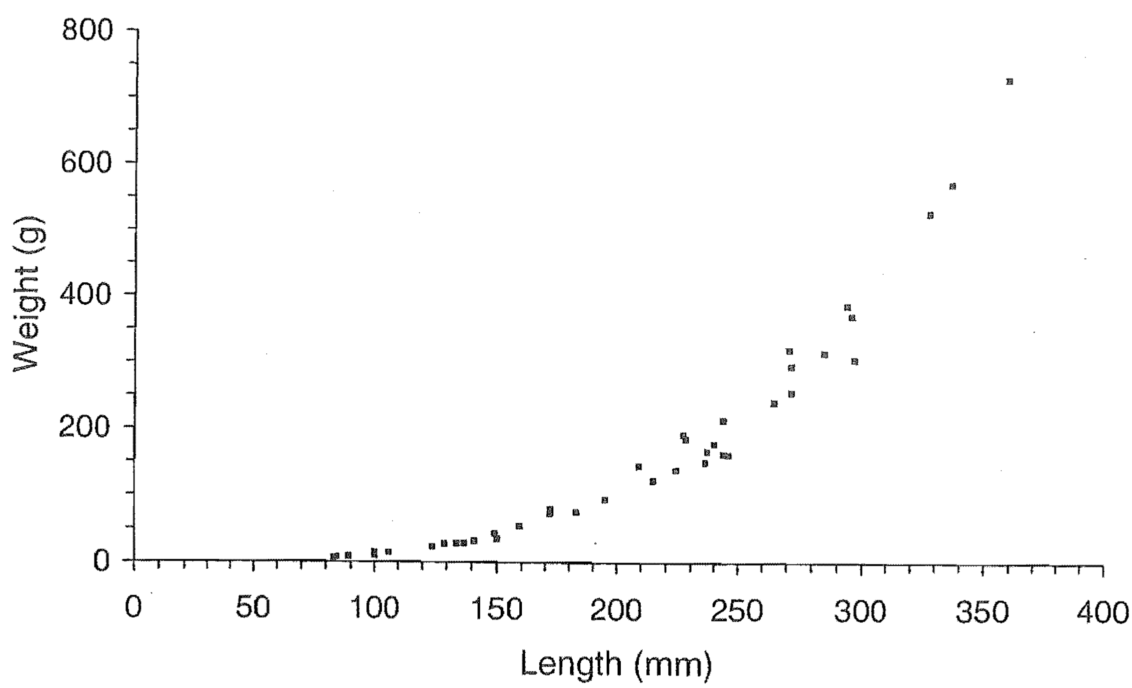

Figure 6. The length-weight relationship of giant kokopu caught in Westland and Southland (N = 40).

2.5 Water type

Giant kokopu have been found in a wide range of water types, including estuaries, lagoons, swamps, streams, drains, rivers, ponds and lakes (Figs 7 - 12). There is really no water type that is "typical" for the species. Usually they are associated with coastal habitats with direct access to the sea, but they also are known to form "landlocked" populations at low to considerable elevations, e.g. in Lake Luxmore, near Lake Te Anau, at over 380 m elevation.

The NZFFD records habitat type, and entries are categorised on the basis of six features:

- Whether the water is flowing or still;
- Whether it is connected to the sea;
- Its source: whether it is fed by rain, snows or springs;
- Its channel type (single or braided) or its outlet type;
- Its size (small, medium or large);
- Whether it is natural or man made;

Examination of habitat types for giant kokopu records on the NZFFD reveals that 483 (86%) came from flowing water. More specifically, 212 (38%) were recorded in small, natural, rain-fed, single channel streams. This appears to be significant, until it is measured against all records on the database; 91% of these are from flowing water and 41% from small, natural, rain-fed, single channel streams. Thus, these data do not show that giant kokopu are expressly choosing such habitats, though they do show that the species is not avoiding them.

One feature does appear to be significant; of the 561 records for giant kokopu, only 3 (0.5%) are from braided streams or rivers, compared to 5% for all fish records on the database. This is consistent with the fact that giant kokopu have never been recorded in any of the braided rivers along the east coast of either the North or South Islands. With this exception, giant kokopu are not apparently associated with any particular water type, so that it seems unlikely that water type

Figure 7. A backwater/lagoon close to the mouth of the Serpentine River, Westland. Adult giant kokopu were caught amongst the partially submerged logs and debris.

Figure 8. A coastal, swampy lagoon that drains into the Arahura river, Westland. Six giant kokopu were caught in one fyke net placed across this channel.

Figure 9. A small coastal stream/pastoral drain in the Catlins. An adult giant kokopu was caught amongst the stream vegetation opposite the dip-net.

Figure 10. Viaduct Creek, a small (<3m wide) bush stream in Westland where giant kokopu were common. Two adult giant kokopu were caught amongst the logs and debris in the centre of the photograph.

Figure 11. A drain connected to Lake George, Southland. Several small (<100mm in length) giant kokopu were caught amongst the instream vegetation.

Figure 12. Lake Kaniere, Westland. Giant kokopu were caught in fyke nets set along the shores.

Figure 13. Ota Creek, a channelised stream in pastoral Southland. Giant kokopu were caught amongst the dense instream vegetation.

is either a critical or limiting factor. It is possible that the presence/absence of certain habitat features are limiting or critical for giant kokopu, whatever the water type.

Intuitively, it appears that giant kokopu occur mostly in systems that contain significant bodies of still water, such as lagoons, lakes or even large ponds. It was not possible to substantiate this using database records, as this feature is not included in the stream type definitions used on the NZFFD. However, the frequency of catches in areas of Westland and Southland, both of which have substantial lagoon and estuary systems, lends support to this hypothesis.

2.6 Stream size

Despite their relatively large size, adult giant kokopu are regularly encountered in very small streams and drains. Stream sizes on the NZFFD are classified by width as small (<10m), medium (10-20m), and large (>20m), and for many of the entries, stream width has been recorded in metres. Of the giant kokopu recorded in flowing water, 250 (52%) were from small streams, and where stream width was recorded it averaged 7.1m. Sampling effort, however, is biased in favour of small streams, because these are more readily sampled than larger bodies of water. Overall, the distribution of stream widths at giant kokopu sites was not independent of those measured at NZFFD sites containing fish ($\chi^2 = 0.136$, df = 36, p = 1.00).

During field surveys, adult giant kokopu were sometimes captured in shallow streams and drains that were less than 1m wide. It was surprising to encounter fish, some of which exceeded 300 mm in length and 0.5 kg in weight, in such confined habitat. This phenomenon was also reported by Haast (1873, page 278) who commented that "often the waterway is so narrow that a large fish like a [kokopu] can scarcely turn around." Nevertheless, there is little evidence to support the suggestion that giant kokopu is a "small stream" fish. They do also occur in large rivers, but are probably less likely to be encountered in these situations using commonly applied sampling techniques.

2.7 Forest absence/presence and type

The NZFFD provides little information on the presence/absence of forest, or on forest type. However, examination of individual records of giant kokopu shows them to occur in a diversity of open and forested habitats, including forested streams and pastoral drains. This is in strong contrast to shortjawed kokopu, which occurs almost exclusively in streams flowing through podocarp/hardwood forests (McDowall et al. 1996a), and banded kokopu, which are not often found in streams lacking a good forest canopy (McDowall 1990) or where the bush has been removed (Phillips 1926).

2.8 Water chemistry

Of the sites where giant kokopu were recorded on the NZFFD, 26% also recorded water temperature and 19% recorded pH, compared to 34% and 17% respectively for all fish sites on the database. There is little difference in the distribution of water temperature frequencies between giant kokopu sites and all NZFFD sites ($\chi^2 = 19.624$, df = 29, p = 0.989), although it appears giant kokopu are not common in warmer waters (Fig. 14). The comparison for pH is more marked ($\chi^2 = 142.316$, df = 16, p = <0.001), and Fig. 15 indicates that giant kokopu are mostly found in low pH (acidic) water. Seventy five percent of giant kokopu records are from water with a pH of less than 7. This certainly fits with the perception that giant kokopu are associated with tannin-stained and acidic waters, but it should be noted that:

- Measuring pH in the field is difficult and frequently inaccurate, especially as some waters are naturally buffered.
- The pH was measured at only a small proportion (19%) of sites, and may have been more likely to be measured in tannin-stained waters when observers thought pH might be a factor affecting fish distribution.
- The values of pH, and also temperature, may simply reflect the distribution of giant kokopu and their relative abundance in Westland and Southland, where waters are generally cooler and quite frequently acidic/tannin-stained.

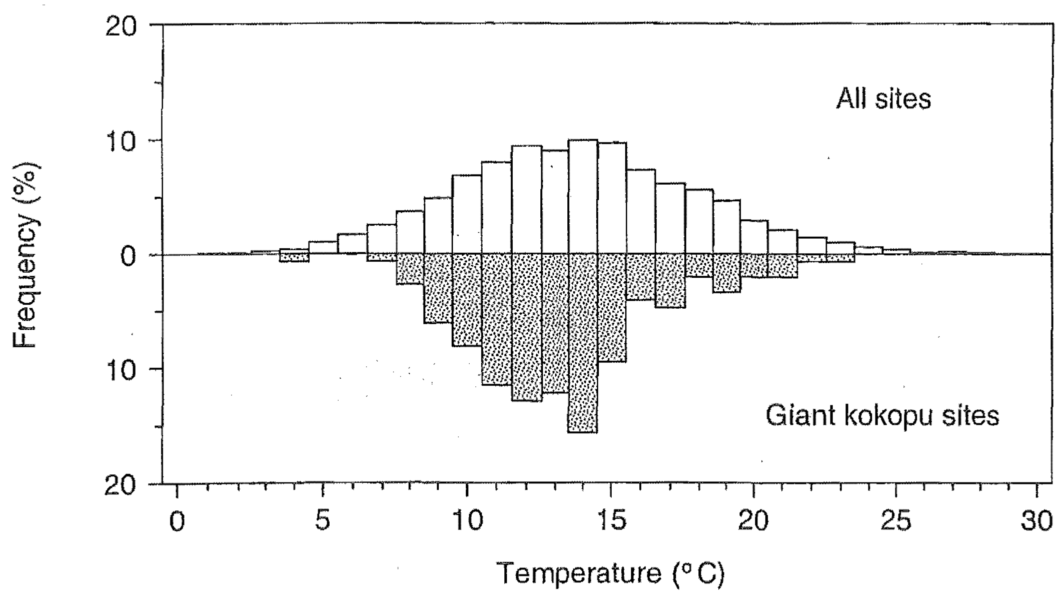

Figure 14. Water temperature at sites where giant kokopu were recorded, compared with temperatures recorded at other NZFFD sites

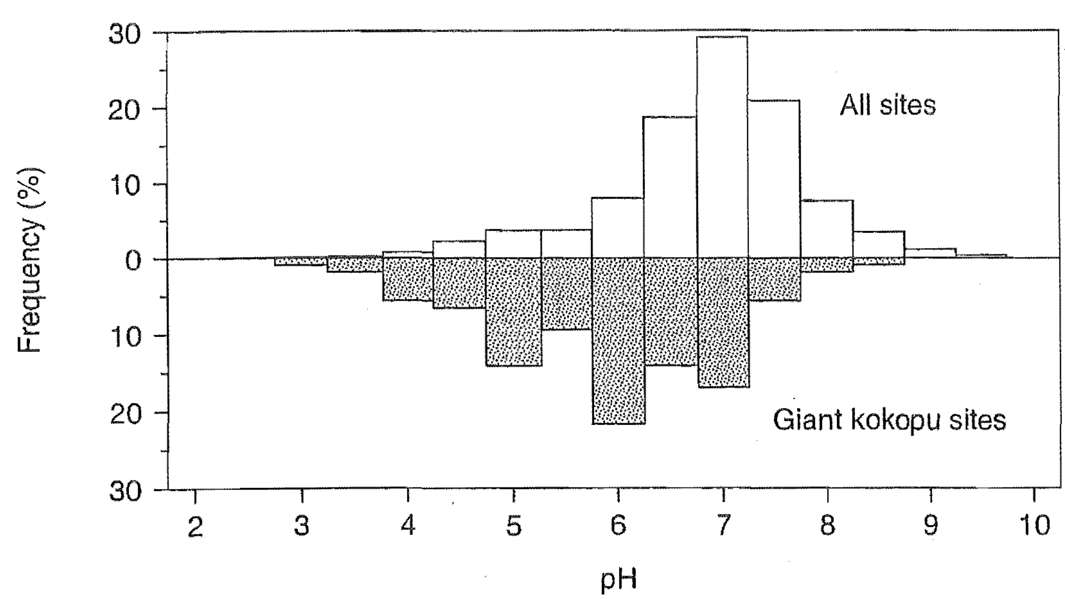

Figure 15. Water pH at sites where giant kokopu were recorded, compared with pH recorded at other NZFFD sites.

2.9 Inland penetration and elevation

The giant kokopu is often regarded as a "lowland" or "coastal" species with little climbing ability, especially when compared to some other galaxiids that are noted for their ability to climb. The NZFFD was used to make comparisons between giant kokopu sites and sites where other fish species were recorded (Figs. 16 and 17). The distributions of both inland penetration and elevation for giant kokopu sites were independent of those measured at NZFFD sites containing fish (for inland penetration $\chi^2 = 83.456$, df = 7, p = <0.001 and for elevation $\chi^2 = 9.665$, df = 12, p <0.001).

The description of giant kokopu distribution as "coastal and lowland" appears to be well founded: 55.6% of giant kokopu records were from elevations of 10m or less, and 59% were from 10km inland or less. Of course, river gradients vary significantly, so that a giant kokopu caught at low elevation does not necessarily mean that it was close to the sea, and vice-versa. However, 58.1% of giant kokopu records are from sites of elevation 10m or less and 10km inland or less (Fig. 18). This distribution may partially reflect sampling effort, which is known to be much more intensive at lower elevations and in areas with easy access.

The number of records from higher elevation and distances inland suggests that some giant kokopu are capable of significant upstream migration. Furthermore, records at 200m elevation or more, but within 20km of the sea, suggest that this species is able to penetrate rivers of relatively steep gradient; 200m elevation at 20km inland equates to a gradient or slope of 10m/km or 1%. In contrast, many of the major rivers in New Zealand, such as the Grey, Manawatu, Waikato, Whanganui, and Whakatane, have gradients of less than 2m/km or 0.2% (McDowall et al. 1996a). It must be noted that records of giant kokopu at extremes of elevation and inland penetration do not necessarily represent sea-migratory fish. Landlocked populations (i.e. with no marine phase) of giant kokopu are known to occur (Lakes Brunner, Mistletoe, Luxmore, George, Horseshoe Lagoon, and others), and in fact may be reasonably common in some lakes (notably hydro lakes such as Lake Monowai, Southland) and isolated ponds.

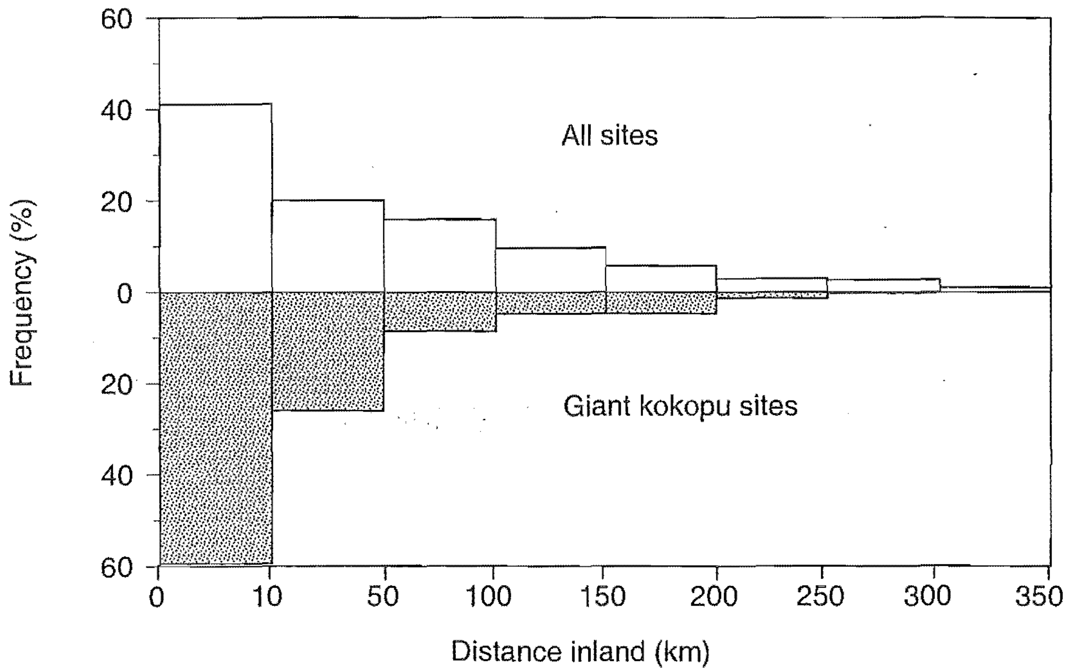

Figure 16. Distance inland at sites where giant kokopu were recorded, compared with distance inland recorded at other NZFFD sites.

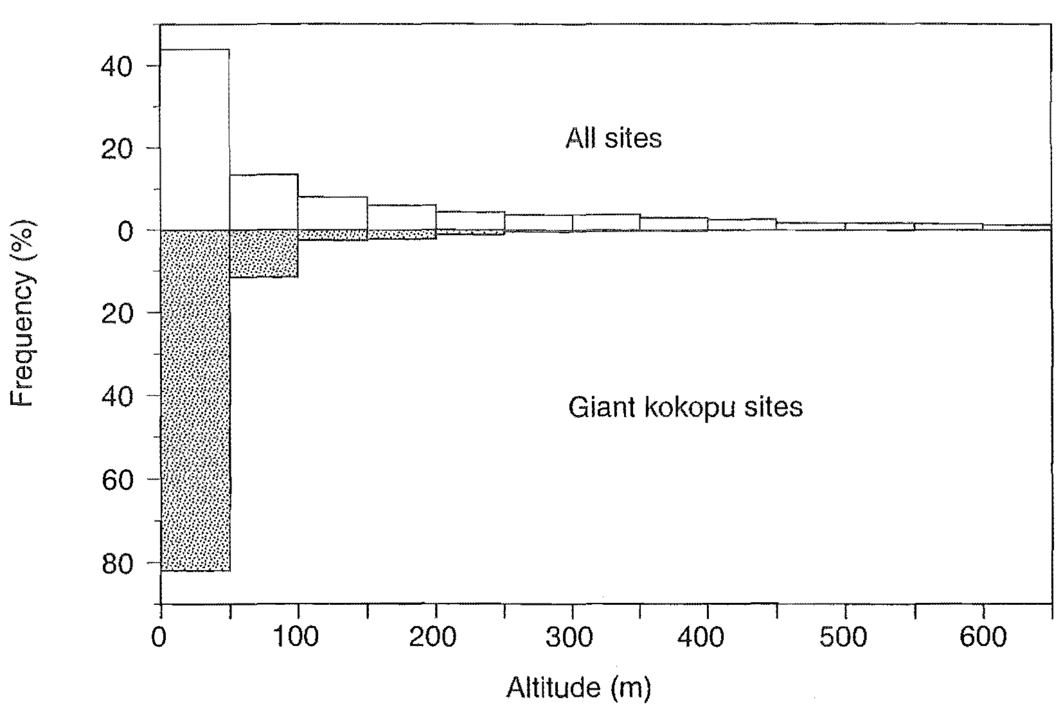

Figure 17. Altitude at sites where giant kokopu were recorded, compared with altitude recorded at other NZFFD sites.

Overall, however, it appears that although giant kokopu are capable of penetrating well inland and ascending significant gradients, they are mostly a low elevation/coastal species.

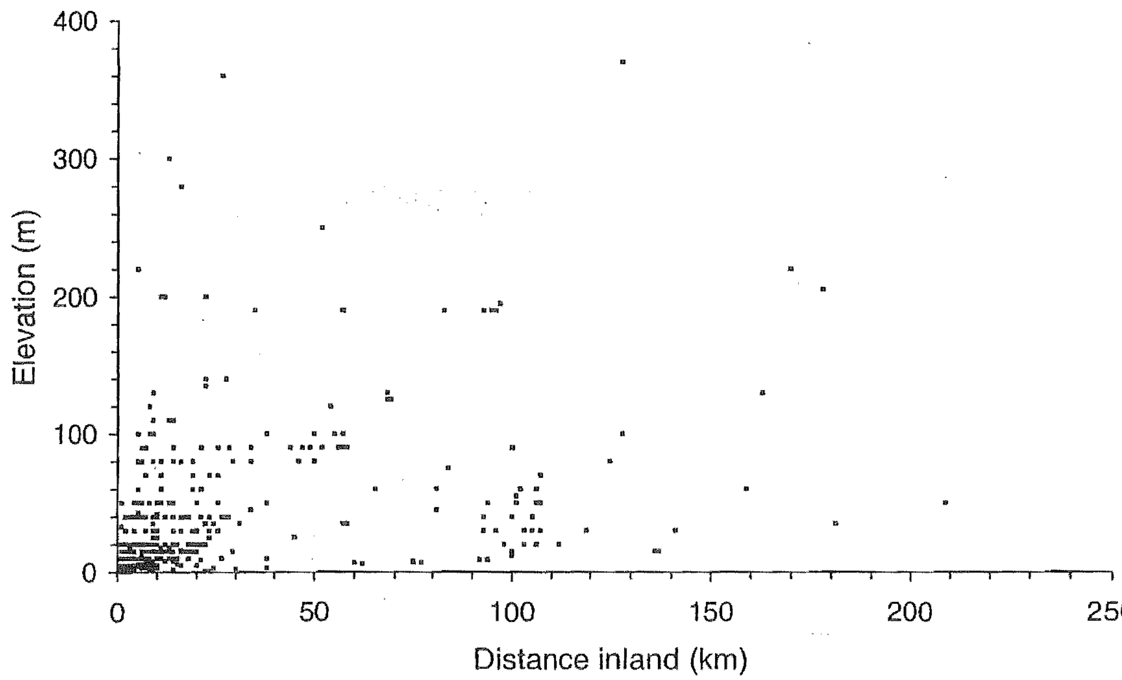

Figure 18. Distance inland versus elevation of NZFFD sites containing giant kokopu.

2.10 Other species associated with giant kokopu

Many indigenous and exotic fish species share the habitats occupied by giant kokopu. The frequency distribution of species richness (the number of species) at sites with giant kokopu is presented in Fig. 19, and is compared with species richness in all sites where one or more species of fish were recorded in the NZFFD. Giant kokopu sites encompass the full range of species richness; in 29% of sites it was the only species recorded, but there are also sites where 10 or more species were present. At some sites, giant kokopu were recorded with up to 17 other species. Overall, the species richness at giant kokopu sites was found to be independent of other NZFFD sites containing fish ($\chi^2 = 25.625$, df = 10, p = 0.004).

The giant kokopu has been found with a total of 33 other species, which further reflects both its wide distribution and ability to utilise a wide range of water types. The species that co-occur with giant kokopu are summarised in Table 1, which lists the common name, the total number of times each occurs on the NZFFD, the total number of co-occurrences with giant kokopu, and the percentages of the respective totals. The ratios of percentage co-occurrence to percentage of total records have been calculated for each species, and provide a "weighted" measure of the significance of the associations. A high ratio implies the species is frequently associated with giant kokopu sites, and species are ranked on the basis of the weighted ratio.

Some species occur frequently with giant kokopu, but are also extremely common; for instance the longfinned eel (*Anguilla dieffenbachii*) occurs in 44.32% of giant kokopu sites, but they also occur in 44.92% of all NZFFD records. Thus, although longfinned eels are the most commonly co-occuring species with giant kokopu, they are ranked 13th in importance, basically because eels occur almost everywhere.

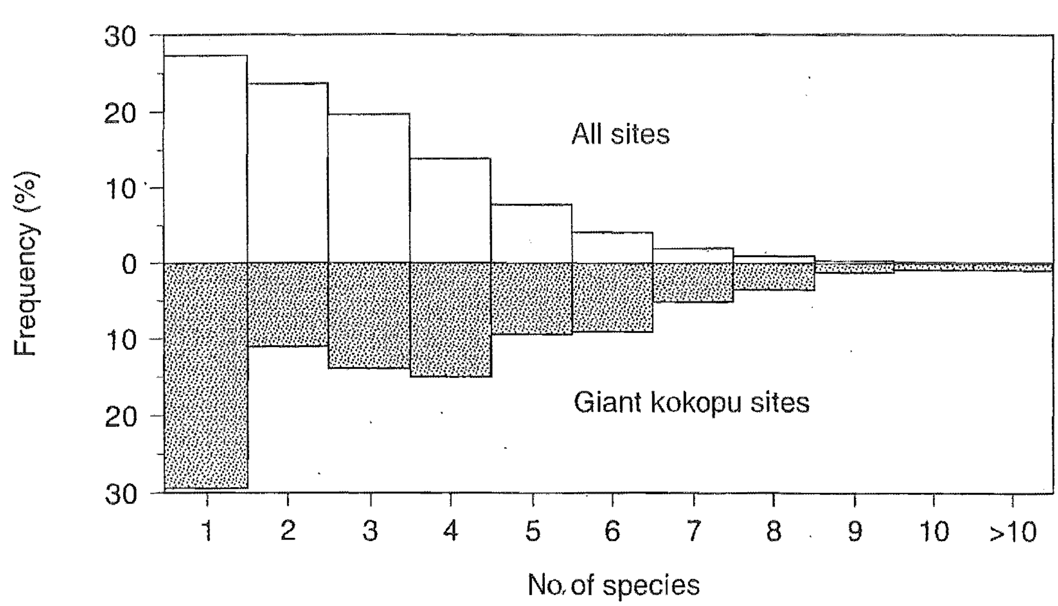

Figure 19. Species richness (number of species) at sites where giant kokopu were recorded, compared to species richness at other NZFFD sites.

Table 1. Other fish co-occuring with giant kokopu from NZFFD records. Excludes grayling (now extinct) for which there was 1 record of co-occurrence with giant kokopu. See text for explanation of ratio and rank.

Common name	No. of co-occurrences with giant kokopu.	No. of records on NZFFD	Percent of giant kokopu records	Percent of NZFFD records	Ratio	Rank
Grass carp	1	6	0.18	0.04	4.06	1
Shortjawed kokopu	30	288	5.35	2.11	2.54	2
Banded kokopu	150	1565	26.74	11.44	2.34	3
Inanga	125	1607	22.28	11.75	1.90	4
Lamprey	33	430	5.88	3.14	1.87	5
Koi carp	4	53	0.71	0.39	1.84	6
Giant bully	19	264	3.39	1.93	1.75	7
Redfinned bully	161	2265	28.70	16.56	1.73	8
Grey mullet	7	100	1.25	0.73	1.71	9
Perch	11	172	1.96	1.26	1.56	10
Shortfinned eel	125	2524	22.28	18.45	1.21	11
Catfish	6	136	1.07	0.99	1.08	12
Longfinned eel	249	6007	44.39	43.92	1.01	13
Common bully	99	2570	17.65	18.79	0.94	14
Koaro	56	1562	9.98	11.42	0.87	15=
Cockabully	2	56	0.36	0.41	0.87	15=
Goldfish	8	286	1.43	2.09	0.68	17=
Mosquitofish	8	288	1.43	2.11	0.68	17=
Bluegilled bully	19	704	3.39	5.15	0.66	19
Black flounder	5	191	0.89	1.40	0.64	20
Rudd	3	118	0.53	0.86	0.62	21
Common smelt	22	913	3.92	6.67	0.59	22
Torrentfish	31	1338	5.53	9.78	0.56	23
Brown trout	94	4299	16.76	31.43	0.53	24
Crans bully	8	543	1.43	3.97	0.36	25
Brown mudfish	2	143	0.36	1.05	0.34	26=
Brook char	1	109	0.18	0.80	0.22	26=
Roundhead galaxias	1	112	0.18	0.82	0.22	28
Rainbow trout	8	1183	1.43	8.65	0.16	29
Yellow-eyed mullet	1	161	0.18	1.18	0.15	30
Dwarf galaxias	1	318	0.18	2.32	0.08	31
Upland bully	4	1537	0.71	11.24	0.06	32

There are so few records of grass carp (*Ctenopharyngodon idella*) on the NZFFD it would be fatuous to attach any significance to this species' ranking. The species which appear to have high affinity for giant kokopu sites are the other two kokopu species, shortjawed and banded. There are a further 10 species with weighted ratios of 1 or more, and when this is considered along with the relatively high species richness at many giant kokopu sites, it implies that giant kokopu is involved in a wide variety of species associations.

It almost appears that giant kokopu co-occur with the majority of all the other freshwater fish species, so it is interesting to note which freshwater fish species giant kokopu have not been recorded with, and speculate on the reasons for them not co-occuring.

Several of these species are virtually restricted to the eastern areas of the South Island, where giant kokopu are seldom encountered. These include:

- Canterbury galaxias (*G. vulgaris*), which is usually found in braided shingle rivers and streams, particularly in high country streams.
- Longjawed galaxias (*G. prognathus*), and alpine galaxias (*G. paucispondylus*), which are small, uncommon, non-diadromous galaxiids that are usually found in inland and alpine streams along the eastern side of the Southern Alps.
- Stokell's smelt (*Stokellia anisodon*), which is found only in the estuaries and lower reaches of the waters of the eastern coast of the South Island, particularly in braided shingle rivers.
- Three species of salmon. Two of these, Atlantic salmon (*Salmo salar*) and sockeye salmon (*Oncorhynchus nerka*) have very restricted ranges and are found only in a few inland areas of the South Island; the other, chinook salmon (*O. tshawytscha*) occurs mostly in the braided shingle rivers of the South Island's east coast.

Several other species occur in Otago and Southland, at mid- or high- elevations that may lessen the probability of co-occurrence with giant kokopu. These species include: flathead galaxias (*G. depressiceps*), dusky galaxias (*G. pullus*) and Eldon's galaxias (*G. eldoni*).

Black mudfish (*Neochanna diversus*) and Canterbury mudfish (*N. burrowsius*) have become specialised to life in habitats that tend to dry up occasionally. Giant kokopu are not known to occur in such habitats.

Some species have extremely restricted distributions, which may significantly diminish their probability of co-occurrence with giant kokopu. These include:

- Dwarf inanga (*G. gracilis*) which is only found in a few dune lakes in Northland.
- Mackinaw (*Salvelinus namaycush*) which is only known from one inland lake in Canterbury.
- Orfe (*Leuciscus idus*) which is presently known from one small lake near Auckland.

Sailfin molly (*Poecilia latipinna*), guppy (*P. reticulata*), and swordtail (*Xiphophorus helleri*), are warm-water exotic species that are mostly restricted to geothermally heated water.

Tench (*Tinca tinca*) is the only species amongst those that do not co-occur with giant kokopu that might be expected to do so. It is known from locations in the lower Waikato, in which giant kokopu occur at many locations, as well as in Northland and near Oamaru, and generally occupies still or sluggish low elevation sites.

2.11 Impact of introduced fish

Of the 21 introduced fish species in New Zealand fresh waters (McDowall 1990), brown trout (*Salmo trutta*) are particularly pervasive, and may be found throughout most of New Zealand. They occur in 94 of the sites where giant kokopu have been recorded (Table 1), which would place them as the seventh most commonly co-occurring species out of 33. However, taking account of the fact that brown trout occur in over 31% of NZFFD records, this species ranks 23rd in order of co-occurrence. It would appear that giant kokopu may be much more likely to occur in habitat where brown trout are absent, as the species co-occur in 16.8% of all giant kokopu sites (conversely brown trout are absent from over 83% of giant kokopu sites).

Overall, there appears to be little affinity between giant kokopu and brown trout, although the two species cannot be said to be mutually exclusive as they do sometimes co-occur.

3 HABITAT SURVEYS AND ANALYSIS OF HABITAT FEATURES

In order to gain explicit and quantitative data on the habitat of giant kokopu, surveys were undertaken in Westland during April 1998 and in Southland (including parts of the Catlins region) during April 1999.

3.1 Methods

3.1.1 Fish capture

Giant kokopu were captured using electrofishing or unbaited fyke nets. A range of habitat parameters was measured or assessed; these included water depth and velocity, water chemistry, substrate composition, physical characteristics of the stream and its banks, and both riparian and instream cover. Measurements were taken at each site where giant kokopu were found, and in adjacent areas where giant kokopu were not found. This provided comparisons and some basis for determining habitat selection; it had to be established which types of habitat were available but were not selected.

In most situations, surveys were carried out using a portable Kainga EFM300 electrofishing machine, which was used to attract and immobilise fish. In streams and drains, electrofishing surveys proceeded in an upstream direction, and as much of the water as possible was sampled. Electrofishing for giant kokopu proved difficult, as most specimens appeared to utilise dense cover such as instream logs and debris, so that fish immobilised by the electric current were not necessarily easy to see and catch. Few of the giant kokopu caught using electrofishing exhibited strong or spectacular reactions to the electric current; there was generally little swimming or splashing and most fish simply became narcotised by the electric current, then rolled onto their side or onto their back. Overall, catch efficiency was probably low.

I observed no fish that may have been damaged by electrofishing, and recovery was usually very rapid. Most giant kokopu were anaesthetised with 2-phenoxyethanol before being measured and weighed, although some fish were sufficiently placid to be handled without anaesthetic. Wherever possible I placed recovering fish into metal "live boxes" in the stream. These had mesh at each end, which allowed a gentle through-flow of oxygenated water, and the metal construction protected fish from further electric shock if electrofishing was still proceeding in the area. Overall, electrofishing proved to be the most suitable method of capturing giant kokopu, particularly as I could "pinpoint" the location of each fish. Unfortunately, the technique is effectively limited to water that is of wadeable depth (approximately <1m deep), so that even in some relatively small streams there were areas that could not be surveyed. The electrofishing method was also inappropriate in turbid water or where water conductivity exceeded about 300 or 400 μScm^{-1}. Thus, muddy drains and/or partly saline waters were only surveyed with fyke nets.

Habitat measurements were made at each location where giant kokopu were caught. For features such as depth and velocity measurements, this could be pinpointed within a few centimetres of where the fish was caught or first seen. Measurements of features such as substrate size, and assessments of habitat features such as cover, were made from an area roughly 1m in radius from the capture point. Habitat measurements were also made at locations where no giant kokopu had been caught. These were selected randomly, after electrofishing or netting surveys, by pacing out set distances from the starting point, e.g. every 20 paces upstream, except where this coincided with a site where giant kokopu had been caught.

It was impractical to survey larger streams, lakes, ponds and swamps by electrofishing, as generally these areas were too deep to be waded safely. The most appropriate technique was the use of fyke nets placed in the water overnight. There were several disadvantages in using this method:

- The fyke nets used were constructed of mesh that was too large to contain small giant kokopu, and the smallest fish caught was 150mm in length. Fish caught in the nets may also have been exposed to the risk of being eaten or injured by large shortfinned and longfinned eels that were a frequent by-catch.

- Their use normally required a return trip and the use of a boat, which was time consuming and inefficient.

- The use of fyke nets was limited to areas of low water velocity, and where there was little instream vegetation and/or debris.

- It was difficult to set fyke nets in uniform habitats, such as lagoons or ponds, in such a way as to provide a range of habitat that giant kokopu may or may not have selected. It was also often very difficult to measure features such as substrate composition in deep and/or turbid water.

The only other method used to survey giant kokopu habitat was observation at night, using a hand-held spotlight. I used a lightweight one million-candlepower light, powered by a sealed 12-volt lead-acid battery. Spotlighting was attempted in a variety of situations, but was only useful in smaller streams where water clarity allowed a reasonable amount of habitat to be seen. Streams that were too deep to electrofish proved too deep for effective spotlighting also. Visibility was also impeded by disturbances on the water surface (e.g. where water was flowing or turbulent) and by the presence of foam on the water surface, which reflected light. Use of a cherry-red filter on the spotlight was useful in these situations.

Fish seen in streams at night could sometimes be caught in a hand-held dip-net, although generally giant kokopu were seldom seen in "open" water away from instream vegetation and debris. By contrast, spotlighting seemed to be an effective method of observing and capturing banded kokopu, which were often seen and readily captured using a hand-held dip net. There was no indication from my spotlight observations at night that suggested stream giant kokopu occupy radically different habitats than during the day, although they might be more active during the hours of darkness.

Spotlighting for giant kokopu would appear to have little advantage over electrofishing in small streams, except perhaps in situations when extreme water conductivity made electrofishing impossible. In the only comparative trial I made, a 220m length of Viaduct Creek, Westland, was surveyed from approximately 2100h to 2200h one evening, and two adult giant kokopu were seen and identified (neither was captured). The same reach was surveyed the following day using an electrofishing machine, and 9 giant kokopu (up to 360mm in length) were caught.

3.1.2 Habitat measurements

Detailed habitat information was collected during the surveys, to determine which features of the habitat were usually selected by giant kokopu. This type of analysis was limited to a narrow range of waters, as detailed information was only available for giant kokopu that were found in water where fish could be readily caught or observed, and where associated habitat features could be specifically identified. Thus, explicit data were readily obtained from electrofishing surveys of small streams and drains, because the location of giant kokopu could be "pinpointed" and features measured. In other areas, such as lagoons and larger streams/rivers, the water was too deep for effective electrofishing and/or spotlight observations, and sampling was undertaken using fyke nets. Less data was obtained from such areas, and they are generally less precise, as the habitat used by any fish could not always be accurately determined or measured.

Water depth and velocity were measured using a Marsh-McBirney electromagnetic water velocity meter mounted on a wading rod. The absence of a propeller or other large mechanical device to measure water velocity allowed measurements to be taken amongst vegetation and stream debris. Measurements of water depth and velocity were averaged from a minimum of three spot measurements taken as close as possible to where each fish was caught. Velocity measurements were made at 60% of the depth below the water surface, as an approximation of mean velocity of the entire water column.

Substrate composition was measured using the Wolman walk method (Mosley 1982), with a minimum of 50 stones measured at each site. Substrate size was expressed as D^{50}, the cumulative size frequency incorporating 50% of the substrate particles measured.

Stream width was measured in metres with a tape measure.

Water chemistry (temperature, pH, conductivity, turbidity, and dissolved oxygen) was measured using a Horiba U-10 multi-parameter water quality checker.

Visual estimates were made of cover composition, bank composition, and substrate embededness and compaction, as there was no practical or reliable method to measure these features. Riparian cover was assessed in several categories by estimating the proportion (%) of the nearest bank that was uncovered (open) or covered by native vegetation, exotic vegetation, scrub, grass, or raupo/flax (a separate category was used for raupo and flax, simply because anecdotal evidences suggested this type of cover was important). Where there was no bank (for instance when a giant kokopu was caught in a lake), all the riparian cover categories were recorded as 0%.

Bank composition was assessed by estimating the proportion (%) of the bank that could be classed as vertical, sloped, undercut, collapsed, slumped, or flat (almost no slope). Again, where there was no bank, each category was recorded as 0%.

Instream cover available to fish was assessed in categories, and an estimate was made of the proportion (%) of the bed covered by each type. The categories of cover used were filamentous algae, substrate, debris, logs, instream vegetation, and culvert/bridge structures.

Substrate embeddedness and compaction were both subjectively rated on a scale of 1-5; where 1 corresponded to little or no embeddedness/compaction, and 5 very embeded/compacted.

3.2 Analyses

The information collected during field surveys may be interpreted at three different levels, as outlined in sections 3.2.1 – 3.2.3

3.2.1 Observations

One distinct benefit in undertaking an intensive habitat survey for giant kokopu was that, with experience, it became possible to predict subjectively, but accurately, where giant kokopu were most likely to be found. This applied particularly to electrofishing surveys in streams and drains, although intuitive predictions were also reasonably accurate for fyke netting and spotlighting operations. While such knowledge proved to be very useful in the field, it had limited use for detailed analysis, and also had the potential to be distracting. I had to take care to sample as wide a range of habitats as possible, and not concentrate on what I thought were "likely" spots.

I observed four features that were regularly associated with the presence of giant kokopu in streams:

- Dense "log-jams" or debris at and below the water surface.
- Areas of low water velocity.
- Relatively deep water, especially in small streams.
- Bank shelter such as undercut banks, very large boulders, bridge foundations, or culverts.

In small streams these features generally occurred in small pools (<$5m^2$) or in areas of gentle flow along the banks. Catching or seeing giant kokopu amongst debris and overhanging bank vegetation is not easy, especially if the water is deep, so perhaps it is not surprising that the casual observer infrequently encounters this species. Giant kokopu that inhabit lagoons, lakes, ponds, swamps and larger rivers may be even less likely to be encountered except by people angling or using fyke nets and/or traps. Thus, overall, giant kokopu abundance may be considerably underestimated.

3.2.2 Habitat analysis

Habitat measurements were recorded in a total of 151 sites, the majority (85%) of which were from flowing water (or lotic) sites. A total of 78 (52%) sites contained giant kokopu, and Table 2 compares the mean values of measured habitat features in all lotic sites from Westland and Southland. Although the mean values do not provide a detailed statistical analysis, they are indicative and they also provide some basis for the later interpretation of multivariate methods.

The mean values indicate that low water velocity may be important for giant kokopu in both Westland and Southland flowing water. Mean water velocity where giant kokopu occurred was less than half that of other sites. It appears that giant kokopu also prefer sites closer to the sea, although this may be a reflection of their preference for the habitats in lowland areas rather than the fish's ability to move upstream.

Several other habitat variables in Table 2 appear to be important for giant kokopu occurrence, but not consistently so for both Westland and Southland sites. These include:

- Riparian vegetation: in both regions it appears that giant kokopu are mostly absent in sites where there is no riparian vegetation (i.e. riparian vegetation = "open"). In Westland, native riparian vegetation seems most important, whereas in Southland raupo/flax (which is also a type of native vegetation) stands out. Most of the Southland streams surveyed were essentially pastoral drains, which contained little native riparian vegetation apart from raupo/flax.
- Instream cover: in Westland, logs and debris appear to be closely associated with the presence of giant kokopu, whereas in Southland instream vegetation and debris were important. Note that Westland streams generally contained comparatively little instream vegetation, and that streams in Southland were essentially pastoral drains, all having been regularly straightened, channelised and cleared. Logs were virtually non-existent but debris and instream vegetation (mostly grasses) were common.

- Substrate size: it appears that giant kokopu may prefer finer substrates, although the association with smaller substrate size may simply reflect a preference for water of low velocity (where smaller substrate may be expected to occur).
- Undercut banks: in Westland it appears that giant kokopu select undercut banks, which supports my subjective observations. In Southland, however, undercut banks were not a feature of the streams/drains surveyed, although in these waterways giant kokopu were often present in and around culverts and bridges. These structures make up a very small proportion of the total available instream cover, so that their utilisation may be significant.
- Shade appears to be significant in Westland, but not Southland. This may partly reflect fish's preference for riparian cover, rather than a preference for shade. In Westland streams, areas with riparian cover (usually bush or forest) were generally well shaded, whereas Southland streams and drains often had abundant riparian vegetation, in the form of grass and scrub, that provided little overhead shade.

From the mean habitat values it appears that giant kokopu occur mostly in low-velocity water, and in areas with significant riparian vegetation. Instream cover is also important, be it logs, vegetation or debris, or the cover provided by structures such as bridges and culverts.

The water chemistry data at giant kokopu sites were not suitable for detailed analysis for two reasons. Firstly, as may be expected in flowing waters, values of temperature, pH etc. were identical for adjacent sites where giant kokopu were and were not present, so that chemical features could not be used to discriminate between sites. In this respect measurements of pH, temperature, conductivity, dissolved oxygen, and turbidity are not strictly "habitat variables" and may not be normally distributed. Secondly, the accuracy of the chemical data (particularly for pH and dissolved oxygen) is questionable; in most cases chemical features were measured with a multi-function water analyser which, despite being frequently and carefully calibrated, gave inconsistent results. Mean values and ranges for the chemical features measured are summarised in Table 3.

Table 2. Mean values of habitat features measured or assessed in Westland and Southland lotic sites where giant kokopu (GK) were absent or present.

	Westland		Southland	
	GK absent	GK present	GK absent	GK present
Feature				
Location				
Distance inland (km)	6.67	5.29	14.4	9.8
Elevation asl (m)	24.7	27.3	7.9	5.6
Chemical features				
Conductivity ($mScm^{-1}$)	0.044	0.049	0.25	0.27
Turbidity (ntu)	3.45	3.43	25.1	17.7
Dissolved oxygen (mgl^{-1})	11.62	11.51	7.12	7.15
Temperature (°C)	11.6	11.9	12.1	11.7
pH	6.81	6.61	5.5	5.6
Physical features				
Water depth (m)	0.32	0.32	0.33	0.31
Water velocity ($msec^{-1}$)	0.12	0.04	0.17	0.07
Stream width (m)	3.66	3.9	2.01	1.81
Substrate size (d50)	43.4	44.7	28.5	1.05
Substrate compactness (1-5)	2.3	2.2	2.1	2.5
Substrate embededness (1-5)	2.3	3.1	4.8	4.6
Bank composition:				
Flat (%)	16	12	0	0
Sloped (%)	57	46	85	89
Vertical (%)	13	10	11	5
Undercut (%)	13	32	0	0
Slumped (%)	1	1	4	6
Riparian cover				
Native vegetation (%)	61	80	0	0
Exotic vegetation (%)	1	0	0	0
Scrub (%)	10	14	38	40
Raupo/flax (%)	0	0	4	13
Open (%)	17	2	9	0
Grass (%)	11	4	49	47
Instream cover				
Overhead shade (%)	45	65	20	17
Filamentous algae (%)	1	0	0	0
Substrate cover (%)	4	8	0	0
Debris cover (%)	4	18	19	18
Log cover (%)	2	19	0	2
Vegetation cover (%)	4	0	17	35
Culvert/bridge cover (%)	0	0	0	1

Table 3. Chemical features of giant kokopu habitat measured during field surveys in Westland (April 1998) and Southland (April 1999).

	Mean	**Minimum**	**Maximum**
Temperature (°C)	11.7	9.1	15.1
pH	6.1	4.1	8
Conductivity ($mScm^{-1}$)	0.157	0.028	0.386
Dissolved oxygen (mgl^{-1})	8.9	4.2	12.8
Turbidity (ntu)	13.8	1	95

3.2.3. Discriminant Functions Analysis

The field surveys were designed to provide data suitable for multivariate analysis, particularly discriminant function analysis (DFA). This technique was identified as being the most suitable for identifying which of the variables measured in the field was critical, and the technique was used to create a statistical model associating habitat variables with the presence of giant kokopu.

A series of analyses was performed on a personal computer using the SYSAT 8.0 statistical software package (Wilkinson 1998). Separate analyses were performed on seven separate groupings of the data (datasets), based on geographical location (Westland or Southland), fish size (juvenile ≤120mm, or adult >120mm), and whether or not the water was flowing. A further analysis was performed using all datasets combined. Data for still water (lentic) sites such as lagoons, ponds and lakes, were generally less accurate, as these areas were sampled with fyke nets. Consequently, a full analysis using only lentic sites was not possible.

In all analyses there were two types of sites; those where giant kokopu were found, and those where they were not. DFA was used to find the combination of habitat variables that best classified (or discriminated between) the two groups. Analyses were carried out in a backwards stepwise manner; initially all the variables were used in the model, then variables that had the least influence on the presence of giant kokopu were successively removed from the model. Results are presented in Table 4. For each analysis, separate F statistic values are listed for the variables (habitat features) which remain in the model after backward stepping. Also listed are jackknifed classification matrix values, which are measures of the success of "self testing" in the model. These are calculated by leaving out single cases to classify the remainder. Thus if there were 100 cases in the model, case x is removed and the remaining 99 cases used to predict if giant kokopu were present for case x or not. All cases are cross-validated in this manner, and the jackknifed values summarise the success of predicting the presence or absence of giant kokopu for all cases in each dataset.

Those habitat variables with consistently higher F-values in all analyses do not necessarily correlate positively to giant kokopu occurrence; they may indicate a correlation with giant kokopu absence. For example "open" riparian cover has high values in six of the eight analyses, but from Table 2 it can be seen that giant kokopu mostly avoid sites where riparian cover was "open".

For most dataset models outlined in Table 4 there are numerous habitat features which appear to be significant. The exception is for the Westland flowing water sites with all fish sizes, for which the DFA model identifies four features as being important: water velocity, overhead shade, substrate cover and log cover.

Habitat variables pertaining to both riparian and instream cover appear to be significant, but not consistently so for each of the datasets. I interpret this as meaning that the presence of some form of riparian and instream cover is important, but that its composition may not be. Furthermore, the lack of consistency possibly reflects differences in habitat features between Southland and Westland sites. Use of variables such as the proportion of native vegetation to predict the occurrence of giant kokopu in Southland is not logical, as the sites surveyed in Southland were virtually all pastoral streams and drains, with riparian vegetation that consisted mainly of introduced grasses and low scrub. Similarly, streams in Westland were mostly bereft of instream vegetation, and this variable could not be expected to be a good predictor of giant kokopu occurrence for the region.

Table 4. Summary of discriminant functions analyses of giant kokopu habitat features. F values are presented for features that discriminated between utilised and non-utilised features. Refer to Table 2 for units of habitat measurements.

Region	------------ Westland		---------		----- Southland	---------		All
Water type	all	flowing	all	all	all	all	all	all
Fish size	all	all	≥120mm	<120mm	all	≥120mm	<120mm	all
Geographical features								
Inland penetration	4.54		3.16		9.58	62.89	8.44	9.08
Elevation						75.29	63.36	
Hydrological features								
Water depth					36.95		53.3	12.6
Water velocity	4.28	2.94	4.83		9.62			10.7
Stream width	6.93		9.07		40.73			4.37
Substrate features								
Substrate size (median)								4.83
Substrate compaction						18.37	7.14	20.2
Substrate embededness			2.69		12.97		67.58	
Bank composition								
Bank flat	5.08		5.21	10.79				
Bank sloped	3.4		3.75	16.57		40.4	9.21	
Bank vertical	2.8		3.18			38.96	17.33	2.92
Bank undercut	4.72		4.9					
Bank slumped								
Riparian cover								
Native vegetation	7.17		5.32	21.4				42.5
Scrub	3.23		2.51		36.07	42.37	3.24	49.9
Exotic vegetation								4
Raupo/flax	14.15		9.25			49.69	13.23	
Open	2.41			4.7	48.83	25.63	4.95	52.9
Grass					58.66		15.43	56.7
Shade cover	7.3	14.04	8.39	15.18	14.09	27.22	23.77	5.34
Instream cover								
Filamentous algae	3.66		5.29	2.24				
Substrate cover	24.74	23.34	22.77	30.92				23.9
Debris cover					37.32	33.54	27.28	
Log cover	48.99	59.53	43.05	54.54	9.93			56.9
Instream vegetation cover					30.83	7.08	19.24	61.7
Culvert/bridge cover					32.23	48.33		9.19
No. of sites fish present	31	21	29	2	25	14	11	56
No. of sites fish absent	30	30	30	30	42	42	42	72
Jackknifed predictions								
% correct absent	97	93	97	100	99	100	98	90
% correct present	87	95	93	0	95	93	100	80
% overall correct	92	94	95	94	98	98	98	86

The utility of the DFA model may also be reduced by the complexity of some variables and the overlap between them. For instance, during field surveys, bank composition was assessed as five separate variables that essentially described a single feature, bank slope. To clarify which features were important, the discriminant functions analyses were repeated using simplified habitat variables. The five variables used to describe the stream bank composition were reduced to one variable, bank slope (% of the banks sloped). Similarly, the six variables describing riparian vegetation were combined into a single variable, riparian vegetation (% of the riparian area covered in vegetation), and the six variables describing instream cover were reduced to one variable, instream cover (% of the bed covered by instream features).

The results of the DFA analyses using simplified variables are presented in Table 5. Simplification of the variables has resulted in a slight loss of "predictability" in the model, as can be seen from the slightly lower jackknifed predictions. However, use of the simplified variables has resulted in a much clearer and consistent model that allows better identification of critical features. From the analyses, using both original and simplified data variables, it is apparent that several habitat features are most frequently and consistently associated with giant kokopu occurrence:

- **Instream cover** is the habitat feature most consistently associated with giant kokopu occurrence. It appears that the composition of the instream cover may not be important. In Westland, logs in the water were the cover that seemed most important, whereas in Southland giant kokopu were consistently associated with instream vegetation, debris and bridge/culvert structures. Generally these factors strongly support the intuitive contention that giant kokopu are a "cover loving" species.
- **Water velocity** was also strongly associated with giant kokopu presence, and fish were almost always found in areas of low velocity. Possibly, water velocity may not be so critical for juvenile fish (<120 mm in length), and smaller specimens may be more tolerant of faster flowing water.

Table 5. Summary of discriminant functions analyses of giant kokopu habitat features using simplified variables. F values are presented for features that discriminated between utilised and non-utilised features. Refer to Table 2 for units of habitat measurements.

Region	Westland				Southland			All
Water type	all	flowing	all	all	all	all	all	all
Fish size	all	all	≥120mm	<120mm	all	≥120mm	<120mm	all
<u>Geographical features</u>								
Inland penetration						2.65		15.47
Elevation					11.49	6.13	19.7	
<u>Hydrological features</u>								
Water depth	5.1		4.65					7.42
Water velocity	7.04	8.9	7.25		22.4	13.54	15.07	20.29
Stream width	2.22							
<u>Substrate features</u>								
Substrate size (median)								
Substrate compaction				2.28	2.29		6.3	
Substrate embededness	2.28		5.15		12.66	13.5	9.75	
<u>Bank composition</u>								
Bank sloped	3.04							
<u>Riparian cover</u>								
Riparian cover			3.61					
Shade cover	32.24	36.42	32.36					11.52
<u>Instream cover</u>								
Instream cover	29.01	46.49	30.76	8.59	20.45	11.31	25.2	54.04
No. of sites fish present	31	21	29	2	25	14	11	56
No. of sites fish absent	30	30	30	30	42	42	42	72
Jackknifed predictions								
% correct absent	87	90	87	93	81	81	88	86
% correct present	94	90	90	50	80	64	73	77
% overall correct	90	90	88	91	81	77	85	82

- **Shade** is also often associated with giant kokopu presence, particularly in Westland, and appears to be, overall, a good predictor of giant kokopu presence. It is logical to regard shade and **riparian cover** together as a habitat feature; areas with dense riparian cover would normally be shaded, and vice-versa. The consistency of the shade variable supports the hypothesis that it is the presence of some form of riparian cover, rather than its composition, which is important. Variables measuring different types of riparian cover were often, but not consistently, associated with giant kokopu presence during the initial DFA, and a lack of riparian cover ("open") was associated with fish absence in both Southland and Westland (Table 2).
- **Inland penetration**; the occurrence of giant kokopu was associated with a lack of inland penetration, especially in Southland waters. Low elevation was also a feature in Southland, and it is fair to say that giant kokopu is predominantly a "coastal" species. That this variable was not so strongly associated with giant kokopu in Westland may be a function of the more restricted range of distances inland and elevations sampled in that region. This may be compounded by the fact that several of the higher/inland areas surveyed contained populations that were probably "landlocked" or non-diadromous. There is a strong implication that inclusion of more habitat data from sites that were much further inland would emphasise the importance of low distance inland to giant kokopu occurrence.
- **Water depth** is also an important feature, although it is probably the least consistent of the group which show strong association with giant kokopu presence. Unfortunately, only a limited range of depths could be effectively sampled during field surveys, so that discrimination based on the water depth variable may have been limited. My subjective observations of giant kokopu in the field indicate water depth as being both important for, and a good predictor of, giant kokopu presence.

Substrate embededness and compaction were variously associated with giant kokopu presence for several datasets, but did not appear to be very important overall. In fact, from Table 2 it is apparent that these two features are unlikely to be good "predictors" of giant kokopu presence, as there is little difference in variable mean values between sites containing giant kokopu and those that do not. It can also be seen that such differences are inconsistent between Westland and Southland cases. Thus it would be difficult to ascertain whether a significant F-value in the DFA model was associated with giant kokopu presence or absence.

3.2.4 Logistic regression

The data collected during field surveys were also suitable for analysis using logistic regression, which, unlike ordinary least squares regression, can be fitted to binary data. In this case the dependant variable, occurrence of giant kokopu, is binary and takes on one of two values corresponding to whether giant kokopu were present or absent. My objective for this analysis was simply to gauge whether the variables identified as being important using DFA would also be identified using a different statistical technique. For clarity, I only applied this technique to the complete set of data, and did not attempt to run separate regressions by region, life stage etc.

The logistic regression was run using the "LOGIT" module of SYSTAT 8.0 (Wilkinson 1998). A series of backward-stepping regressions was used, so that initially the model used all the available variables. On each successive iteration, the least significant variables were removed until a set of the "best predicting" variables remained. Initially there were too many variables for the stepping procedure to run successfully, but the results presented in Table 6 were obtained using the dataset with simplified and reduced variables.

The five variables identified by DFA exactly match those identified by logistic regression, which emphasises the importance of instream cover, water velocity, shade/riparian cover, inland penetration and water depth.

Using logistic regression, the significance of each variable is not tested with jackknifed cross-validation, but the "reliability" of each variable can be assessed using coefficient values, standard errors, t-ratios, probability values, and odds ratios with upper and lower bounds at 95% confidence limits. A coefficient that is large relative to its standard error will have a higher t-ratio and is likely to be a better predictor. However the odds ratio may be a more meaningful measure for each coefficient. The odds of the response (prediction) are given by $p/(1-p)$, where p is the probability of response, and the odds ratio is the multiplicative factor by which the odds change when the independent variable increases by one unit. Thus, the measurement units of the variable are important when assessing the odds ratio. For the giant kokopu model, an increase in water depth of 1m increases the odds of giant kokopu occurring by a factor of 3.795. However, this should be viewed with caution since there are large bounds on the ratio, and the lower bound is less than 1; so water depth may not be such a reliable predictor as the odds ratio would indicate. Note that t-ratios for both inland penetration and water velocity are negative, so that the model predicts that giant kokopu are less likely to occur with increasing distance from the sea or with increasing water velocity.

Table 6. Logistic regression results for five habitat features; see text for full explanation of statistics presented.

Habitat Feature	Regression coefficient	Standard error	t-ratio	p	Odds ratio	95% bounds upper	lower
Instream cover (%)	0.071	0.015	4.863	<0.001	1.073	1.104	1.043
Water velocity ($msec^{-1}$)	-10.614	3.182	-3.336	0.001	0	0.013	0
Inland penetration (km)	-2.614	0.92	-2.842	0.004	0.943	0.977	0.911
Water depth (m)	1.334	0.733	1.819	0.069	3.795	15.969	0.902
Overhead shade (%)	0.023	0.008	2.691	0.007	1.023	1.04	1.006

Some variables were limited in range, so that neither DFA nor logistic regression may present a full picture. If a greater range of sites could have been effectively surveyed and analysed, some variables may have been shown to be more or less important. The narrow range of a number of features (e.g. depth) reflects the dominance of records from small, easily sampled streams. I cannot speculate on how different any DFA or logistic regressions might be if they included more data from, for instance, coastal lagoons, estuaries and lakes.

The objective of the analysis was always to identify which of the habitat features are important for giant kokopu, rather than construct a more quantitative model for predicting the abundance of giant kokopu. Such a model would have to be based on more quantitative data, e.g. biomass per unit area, rather than presence/absence information. This in turn would probably require considerably more fieldwork to collect sufficient data.

4. OBSERVATIONS ON THE USE OF COVER

4.1 Experimental structures

During field surveys, I observed that in several small Westland streams giant kokopu were relatively common, but almost always only found under and amongst dense accumulations of logs and debris. Logs that had accumulated around large boulders, or on stream banks, seemed to form habitat with dense instream cover and areas of low water velocity. It appeared that instream cover and low water velocity were important features for giant kokopu, and that both of these features may have significant implications for the management and conservation of the species.

To test my hypothesis that these two features were the "keys" to giant kokopu occurrence, six artificial habitats were constructed within a 200m reach of Viaduct Creek, a small lowland tributary of the Arahura River, Westland. The artificial habitats were constructed using metal fencing standards ("waratahs") driven into the streambed and banks. To these I attached logs (mostly fallen branches from native bush) with steel wire, to form almost a platform near the water surface (Fig. 19). Some of the logs were placed close to the streambed, and created an area of 1-2 square metres of dense instream cover which fish could occupy. In sites where water velocity was thought to be too great for giant kokopu, boulders were moved close to the structure to create zones of low water velocity.

These structures were created in December 1998, and left for approximately three months to accumulate natural stream debris. One of the structures was destroyed by high stream flows, and the remaining five were surveyed in March 1999, and again in May 1999. Results of both surveys are summarised in Table 7. During the May survey, a 220m reach of Viaduct Creek including the five structures, was carefully electrofished. A total of eight giant kokopu were caught, including the four utilising the artificial structures.

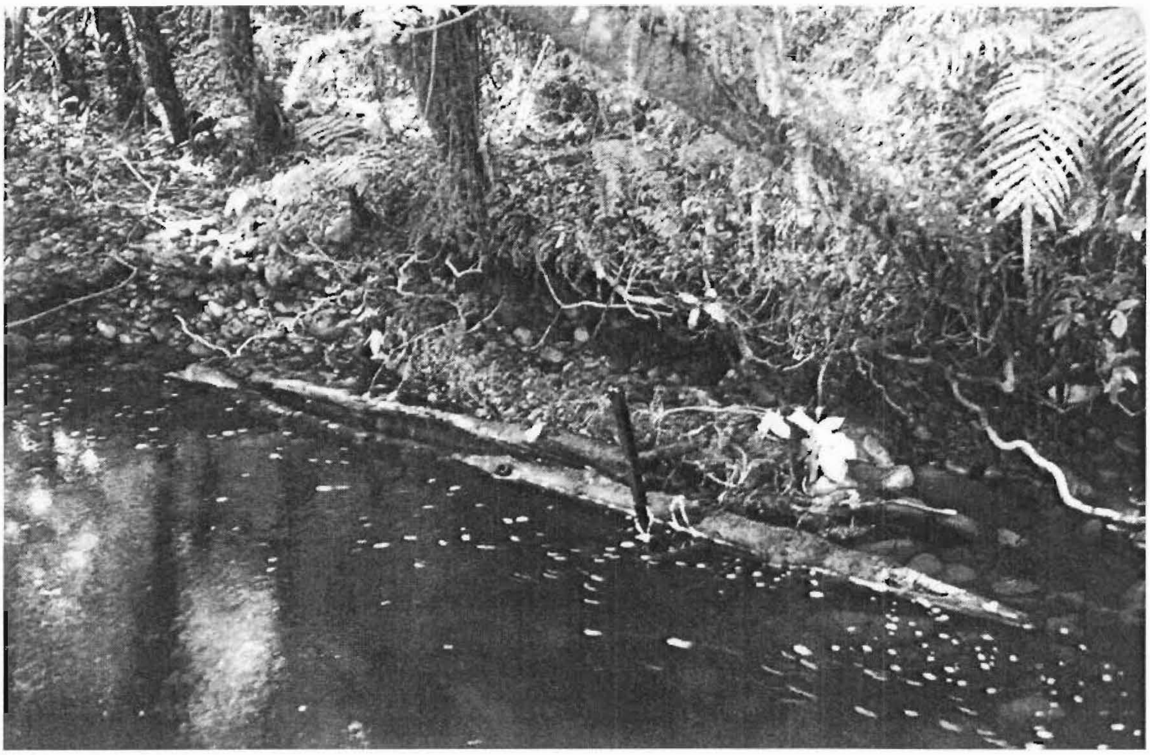

Figure 20. The edge of a pool in Viaduct Creek, Westland before (upper) and after (lower) the construction of an "artificial" habitat structure. Logs were attached to waratahs driven into the streambed and banks, and covered an area of approximately 2.5m x 0.8m. On each of two subsequent surveys, two giant kokopu were found under this structure.

Table 7. Water depth, water velocity (both measured 3/3/1999), and size of giant kokopu captured under artificial habitat structures in Viaduct Creek, Westland. For clarity structures are labelled from (a) at downstream end of reach to (f) at upstream end.

Structure	Mean water depth (m)	Mean water velocity (m.sec^{-1})	Giant kokopu length, 3/3/99	Giant kokopu length, 13/5/99
a	0.3	0.01	295mm	
b	0.17	0.19	--- structure destroyed by flood before 3/3/99 --	
c	0.13	0.03	192mm	
d	0.28	0		337mm
e	0.24	0		240mm
f	0.37	0	332mm,305mm	183mm,137mm

This experiment lends support to the hypothesis that giant kokopu utilise habitat with dense instream cover and low water velocity. Giant kokopu were present in areas which had not been previously used, and although it was not practicable to control for changes over time, it seems unlikely that these fish would have appeared in the experimental areas for any other reason than these areas now provided suitable habitat. It would be feasible to conduct a more detailed study using artificial structures, and to examine habitat selection and utilisation more rigorously, but such a major experiment was outside the scope of this project.

Although these structures appeared to "attract" giant kokopu, I knew from previous surveys that the stream already supported a population of these fish, and creating artificial habitat would not necessarily increase the carrying capacity of the stream. Nor was the experiment designed to promote the use of habitat structures in other streams or waterways that are perceived to require habitat enhancement, although such an approach may well provide a useful means of enhancement where suitable habitat is limited.

The major objective of this study was to identify critical habitat features, and the successful use of artificial habitats simply supports the hypothesis that instream cover and low water velocity are critical. Subsequently, multivariate analysis has shown that other features (shade, inland penetration and water depth) are also important, and it is interesting to note that the structures were not limited by these features in Viaduct Creek, which was close to the sea, had abundant overhead shade from native bush and forest, and included a natural range of water depths.

During both the February and May surveys, banded kokopu and redfin bully were also observed in the experimental structures, particularly in those where giant kokopu were absent. By the time of the May survey, all of the structures appeared to have become slightly degraded; most had acquired a dense accumulation of debris, and several were beginning to fill with gravel and fine streambed materials. There may also have been some changes to the streambed near the structures, as the built up materials had appeared to cause the main flow of the stream to move away from the structures. Consequently, I dismantled and removed all the structures from the stream.

4.2. Vegetated and open shores

There is some anectodal evidence that giant kokopu in lakes are mostly associated with vegetated rather than open shores (C. Tonkin, West Coast Fish & Game Council, pers. comm.). Statistical analyses have demonstrated that overhead shade and riparian vegetation are important for giant kokopu in flowing water, and that there is a strong association between "open" banks and absence of giant kokopu. To test this in still water, 10 fyke nets were baited with "Marmite" (a common yeast extract) and set overnight along vegetated and open beaches of the eastern shores of Lake Kaniere, Westland, on the nights of 12-13 May and 13-14 May 1999.

A total of 13 giant kokopu were caught in the fyke nets, along with 58 eels and eight perch (Table 8). The slight differences in catch rates between vegetated and open shores were tested using a two-sample t-test, and found to be not statistically significant ($p = 0.25$). Thus the results do not support the hypothesis that giant kokopu are associated with vegetated shores. It is possible that giant kokopu in

Lake Kaniere are more common near the mouths of tributary streams and/or in areas where there is dense underwater cover. It would be difficult to distinguish these features from the effect of vegetated shores without substantial effort and a carefully designed experiment.

Table 8. Catch per unit effort (catch/net/night) along vegetated and unvegetated shores of Lake Kaniere, Westland, May 1999.

	Unvegetated shore				**Vegetated shore**			
	giant kokopu	longfinned eel	shortfinned eel	perch	giant kokopu	longfinned eel	shortfinned eel	perch
Total catch	5	29	1	2	8	26	2	6
Catch/net/night	0.5	2.9	0.1	0.2	0.8	2.6	0.2	0.6

5. GIANT KOKOPU DIET

This study concentrates on the association of habitat features with the occurrence of giant kokopu, but it is also worthwhile to speculate on the reasons for any such associations. One possible reason is the capacity of the habitat to supply food for the fish, and it was deemed worthwhile to investigate the diet of giant kokopu. Of particular interest was the proportion of the diet comprising invertebrates of terrestrial (versus aquatic) origin, as invertebrate input is likely to be influenced by riparian characteristics (Edwards and Huryn 1995).

The gut contents of 105 giant kokopu were examined. These fish had been collected between approximately 1963 and 1994 from various locations around New Zealand, including the Chatham Islands. All fish were preserved in formalin, and stored initially in the collection of the New Zealand Ministry of Agriculture and Fisheries and, subsequently, NIWA. Fish ranged in (preserved) fork length from 42 to 384mm (mean 216mm). For many of the specimens only a general location of capture was recorded (e.g. "West Coast"), and in some instances neither location nor date of capture was specified. The method of capture was also infrequently specified, but did include electric fishing, fyke netting, gill-netting, and angling with live bait. Table 9 summarises the size of the fish examined by broad geographical regions.

Table 9. Lengths of giant kokopu used for gut contents analysis, categorised by geographical region. Fish were captured from approximately 1963 to 1994 using a variety of methods.

		Length (mm)		
Region	N	Minimum	Maximum	Mean
Canterbury	2	267	292	279.5
Chatham Islands	5	66	384	205.2
Wellington	10	42	336	132
Westland	79	51	368	224.6
Unspecified	9	54	321	226.7
All	105	42	384	216

Of the 105 fish examined, 14 had no gut contents, and the remaining 91 contained a total of 3169 food items (Table 10). The wide variety of food items identified may in part be a function of the variety of fish sizes, collection sites and seasons in the sample. However, giant kokopu also appear to be generalistic and opportunistic carnivores, a trait common in galaxiids (McDowall 1990).

Few of the 78 food items listed in Table 10 could be said to dominate the diets of giant kokopu. By abundance, aquatic Trichoptera, Gastropoda, and Hemiptera comprised 29.1%, 12.6% and 14.4% of the diets respectively, while terrestrial Coleoptera comprised 12.2%. A further eight food categories comprised > 1% of the diets; Nematoda (6.3%), Diptera (5.2%), Arachnida (4.4%), Ephemeroptera (2.7%), Hymenoptera (2.6%), Osteichthyes (1.9%), Lepidoptera (1.6%), and Diplopoda (1.1%).

Information from this study was summarised in Table 11 and compared to other studies of giant kokopu diet by Jellyman (1979), Main (1988), and Rasmussen (1990). These varied considerably with respect to the importance of food items of terrestrial origin. From the present study, terrestrial items comprised a significant component of the diet, as they occurred in 76 (83.5%) of the 91 fish containing food, and comprised 25% of the diet by abundance. From the reports of Main (1988) and Rasmussen (1990), it appears that terrestrial items comprise a greater proportion of the diet in lotic habitats than in lentic, as in both studies terrestrial items occurred 4-6 times more frequently in lotic environments. Jellyman (1979) reported that terrestrial items comprised 84.1% of giant kokopu diet in Lake Pounui, Wairarapa, but cautioned that all six fish used in his study were caught a few days after a major flood, which increased foraging area and may have resulted in some bias towards terrestrial food in the diet. The diets of 19 giant kokopu from lotic environments in the Waikato region were examined by West (1989), and found to be dominated by terrestrial prey items both numerically and gravimetrically (68% and 90.4% respectively), although details of diet composition were not fully reported.

Table 10. Summary of gut contents of 105 preserved giant kokopu. Frequency = total no. of each taxa in all fish; %frequency = frequency as a proportion of total no. of taxa. Occurrence = total no. of fish containing each taxa; %occurrence = proportion of all fish containing each taxa. (A) = adult, (P) = pupa, and (L) = larva.

Taxa	Frequency	Occurrence	% frequency	%occurrence
Aquatic foods				
NEMATODA	198	18	6.25	17.14
NEMATOMORPHA	17	10	0.54	9.52
AMPHIPODA	22	9	0.69	8.57
DECAPODA				
Paratya curvirostris	18	7	0.57	6.67
Paranephrops zealandicus	2	1	0.06	0.95
GASTRAPODA				
Potamopyrgus antipodarum	398	13	12.56	12.38
Gyraulus corinna	1	1	0.03	0.95
ODONATA	15	9	0.47	8.57
TRICHOPTERA				
Beraeoptera roria	1	1	0.03	0.95
Olinga feredayi	20	6	0.63	5.71
Helicopsyche spp.	8	4	0.25	3.81
Hudsonema amabilis	6	1	0.19	0.95
Oxyethira albiceps	24	5	0.76	4.76
Paroxyethira hendersoni	184	6	5.81	5.71
Zelandopsyche spp.	15	1	0.47	0.95
Philorheithrus agilis	3	1	0.09	0.95
Pycnocentria evecta	42	11	1.33	10.48
Pycnocentria spp.	18	3	0.57	2.86
Pycnocentrodes spp.	1	1	0.03	0.95
Pycnocentrodes aureola	4	3	0.13	2.86
Triplectides obsoleta	399	22	12.59	20.95
Triplectides cephalotes	18	2	0.57	1.90
unidentified case caddis	19	13	0.60	12.38
unidentified free living caddis	26	9	0.82	8.57
Aoteapsyche colonica	8	3	0.25	2.86
Hydrobiosis spp.	21	3	0.66	2.86
Hydrobiosis spatulata	2	1	0.06	0.95
Hydrobiosis umbripennis	2	1	0.06	0.95
Polyplectropus spp.	1	1	0.03	0.95
Psilochorema spp.	90	3	2.84	2.86
unidentified Trichoptera (A)	4	2	0.13	1.90
unidentified Trichoptera (P)	5	1	0.16	0.95
EPHEMEROPTERA				
Austroclima sp.	1	1	0.03	0.95
Deleatidium spp.	4	2	0.13	1.90
Coloburiscus humeralis	53	2	1.67	1.90
Oniscigaster wakefieldi	2	2	0.06	1.90
unidentified Ephemeroptera (L)	23	4	0.73	3.81
unidentified Ephemeroptera (P)	1	1	0.03	0.95

Table 10 continued

Taxa	Frequency	Occurrence	% frequency	%occurrence
HEMIPTERA				
Anisops sp.	7	6	0.22	5.71
Diaprepocoris zealandiae	425	13	13.41	12.38
Sigara sp.	22	6	0.69	5.71
Microvelia macgregori	1	1	0.03	0.95
PLECOPTERA				
unidentified Plecoptera (L)	1	1	0.03	0.95
Zelandoperla decorata	4	1	0.13	0.95
COLEOPTERA				
Coleoptera (L)	3	3	0.09	2.86
Coleoptera (A)	7	5	0.22	4.76
MEGALOPTERA				
Archichauliodes diversus	2	2	0.06	1.90
COLLEMBOLA	2	2	0.06	1.90
DIPTERA				
Austrosimulium tillyardianum (L)	51	1	1.61	0.95
Austrosimulium tillyardianum (P)	4	1	0.13	0.95
Ceratopogonidae	1	1	0.03	0.95
Chironomidae (L)	59	12	1.86	11.43
Chironomidae (P)	30	13	0.95	12.38
Chironomidae (A)	2	1	0.06	0.95
Muscidae	1	1	0.03	0.95
Stratiomyidae	11	5	0.35	4.76
unidentified Diptera (L)	5	4	0.16	3.81
OSTEICHTHYES				
Unidentified fish remains	61	27	1.92	25.71
Terrestrial foods				
OLIGOCHAETA	3	3	0.09	2.86
DIPLOPODA	34	5	1.07	4.76
ARACHNIDA	49	18	1.55	17.14
Acarina	1	1	0.03	0.95
Araneida	89	22	2.81	20.95
DIPTERA				
unidentified Diptera (A)	25	15	0.79	14.29
COLEOPTERA				
Coleoptera (A)	361	62	11.39	59.05
Coleoptera (L)	27	14	0.85	13.33
LEPIDOPTERA				
Lepidoptera (L)	20	7	0.63	6.67
Lepidoptera (P)	2	2	0.06	1.90
Lepidoptera (A)	28	4	0.88	3.81
DERMAPTERA	1	1	0.03	0.95
HYMENOPTERA	83	25	2.62	23.81
HEMIPTERA	30	18	0.95	17.14
ORTHOPTERA	18	16	0.57	15.24
BLATTODEA	15	8	0.47	7.62
ISOPODA	6	3	0.19	2.86
MOLLUSCA	2	1	0.06	0.95
Total	3169	515		
Mean				
Aquatic	22.6	2.8	74.9	56.3
Terrestrial	7.6	2.1	25.1	43.7
Total	30.2	4.9		

Table 11. Summary of giant kokopu diet from fish examined in this study compared to diets described by Jellyman (1979), Main (1988), and Rasmussen (1990).

Study	This	Main	Jellyman	Rasmussen	Main	Rasmussen
Habitat type	various	lentic	lentic	lentic	lotic	lotic
Collected	1963-94	1984/85	1978	1988	1986	1988
N	105	24	6	16	11	14
Category						
<u>Aquatic</u>						
ARACHNIDA				1.2		
COLEOPTERA	0.32	0.1	0.4	2.2	0.9	1.9
COLLEMBOLA	0.06					
CRUSTACEA	0.69	0.8	0.4	7.3		38.3
DECAPODA	0.63					
DIPTERA	5.18	0.6				7.5
EPHEMEROPTERA	2.65				4.7	
GASTROPODA	12.59			61.7		
HEMIPTERA	14.36	68.9	9	15.1		8.4
MEGALOPTERA	0.06				0.9	
NEMATODA	6.25					
NEMATOMORPHA	0.54		1.3		13.2	
ODONATA	0.47	8.6	0.4	4.4		2.8
OLIGOCHAETA				1.2		
OSTEICHTHYES	1.92	4	4.4	1.5	1.9	2.8
OSTRACODA				0.7		
PLECOPTERA	0.16				0.9	
TRICHOPTERA	29.06	4.9		0.7	19.8	13.1
<u>Terrestrial</u>						
ANNELIDA	0.09	0.1				
ARACHNIDA	4.39	1.9	19.3		9.4	10.3
COLEOPTERA	12.24	3.8	12.4	0.2	24.5	13.1
DERMAPTERA	0.03		0.4	0.5		
DIPLOPODA	1.07		0.9			
DIPTERA	0.79	0.7	40.8	2.7	0.9	
HEMIPTERA	0.95	0.6	1.3		1.9	
HYMENOPTERA	2.62	0.3	8.6		11.3	0.9
ISOPODA	0.19					
ISOPTERA		4.3				
LEPIDOPTERA	1.58		0.4		1.9	
MOLLUSCA					0.9	
MYRIAPODA				0.5	4.7	0.9
ORTHOPTERA	1.05	0.4			2.8	
% aquatic	**74.9**	**87.9**	**15.9**	**96.1**	**42.0**	**74.8**
% terrestrial	**25.1**	**12.1**	**84.1**	**3.9**	**58.0**	**25.2**

The importance of terrestrial items in the diet of giant kokopu may partly explain the significance of overhead shade and riparian vegetation to this species. Main and Lyons (1988) reported that banded kokopu fed predominantly on terrestrial prey, which comprised 90.9% of gut contents gravimetrically, and suggested that riparian vegetation provided an important source of prey. Cadwallader et al. (1980) suggested that woody vegetation was an important source of terrestrial food for the Australian mountain galaxias (*G. olidus*), and Main (1988) concluded that forest vegetation would be expected to make a very significant contribution to the diets of stream-dwelling kokopu by acting as a primary source of invertebrates. Shortjawed kokopu favours streams with heavy riparian forest cover (McDowall et al. 1996a), and although its diet is variable, McDowall et al. (1996b) reported that their nutrition was mostly derived from terrestrial prey.

Eldon (1969) noted that, in aquaria, giant kokopu often fed at the water surface, while Main (1988) reported that they maintained station near the water surface and took food falling through the water column. Clark (1899) reported that giant kokopu lay close to the water surface and rose to take flies, and Haast (1873) reported them to be easily captured using a grasshopper as bait. Banded kokopu (*G. fasciatus*) are known to have similar feeding habits (Eldon 1969; Main 1988), and McDowall (1997) suggests that the presence of bilateral accessory lines in New Zealand and Australian galaxiids (including all three kokopu species) may assist these fish in locating terrestrial foods on the water surface.

Terrestrial food items have been reported to be of lesser importance in the diet of other New Zealand galaxiids (*G. maculatus* - Allen 1951, McDowall 1968a; *G. vulgaris* – Cadwallader 1975a; *G. divergens* – Hopkins 1971a; G. *paucispondylus* and *G. prognathus* – Bonnett et al. 1989; *Neochanna apoda* – Eldon 1978; *N. burrowsius* – Eldon 1979).

One interesting component of diet was fish; 26% of the giant kokopu examined in this study contained fish remains. Fish may be relatively heavy compared to most of the other common invertebrate food items, and could comprise a significant component of the diet on a gravimetric basis. Main (1988) found that in Westland lotic environments, giant kokopu prey biomas was dominated by fishes including inanga (*Galaxias maculatus*) and common bully (*Gobiomorphus cotidianus*), although these formed only 4% of the diet by abundance. Jellyman (1979) reported that in Lake Pounui, Wairarapa, giant kokopu diet included eels and other unidentified fish remains comprising 22.6% of the diet by weight. The diet of some giant kokopu in Southland included perch (*Perca fluviatilis*) and other giant kokopu varying in size from 25 to almost 200mm in length (Rasmussen 1990). This is not the first instance of cannibalism amongst galaxiids, as Meredyth-Young and Pullan (1977) found *G. brevipinnis* fry in the stomach of adult fish from Lake Chalice, Marlborough. New Zealand's native fish fauna contains no specialised piscivores (McDowall 1968b), and although it appears that giant kokopu is a generalistic feeder, fish may be a significant component of the diet.

6. DISCUSSION AND CONCLUSIONS

6.1 Limiting factors

In recent times giant kokopu has been regarded as a rare or uncommon species, and it has been classified as threatened in the New Zealand Red Data Book on Fishes (Williams and Given 1981). In many areas (e.g. South Canterbury) it is now very infrequently encountered, despite being common enough for early settlers to be interested in giant kokopu as a food item (Anderson 1916). The decline in numbers and distribution of giant kokopu in developed areas has been attributed largely to loss of habitat following agricultural and urban development (McDowall 1984a; 1990), and there is an underlying assumption that giant kokopu are limited by habitat availability.

There may be other factors that are limiting, and to consider these it is appropriate to first review the life history of the species. Some aspects are not well understood, but the probable life cycle of diadromous giant kokopu can be summarised as follows:

- Adult fish reside in fresh or estuarine water.
- Spawning takes place mainly in June – August, probably in areas close to the sea.
- Fry hatch and are washed out to sea.
- The fry develop in salt water over the late winter/early spring.
- They migrate into estuarine or fresh water as whitebait, mainly during November and December.
- Juvenile fish develop in fresh water and grow into adults.

Factors that may limit giant kokopu could occur at several stages of the life cycle. Although the spawning habitats and requirements of the species are unknown, ripe fish have been reported in or close to "normal" habitat by Jellyman (1979) and McDowall (1990), which suggests that adults do not migrate far to spawn. Until more is known of giant kokopu spawning, I can only speculate whether the availability of suitable spawning habitat may or may not be limiting. Possibly giant kokopu require very specific spawning habitat, which could be limiting. Landlocked populations survive without access to separate estuarine spawning habitats, and in these cases it appears that separate spawning habitat is neither critical nor limiting.

Very little is known of the marine phase of the life cycle, from hatching through to re-entering fresh water as whitebait. McDowall and Eldon (1980) noted that fluctuations in the annual whitebait catch (comprising five species of *Galaxias*) could be the result of environmental conditions during spawning and early development, conditions in the sea that may affect the survival and dispersal of fish, and river conditions during the period the fish migrate into freshwater. Whether any of these factors might limit giant kokopu cannot be easily determined.

Giant kokopu whitebait are exploited during the upstream migration from the sea to freshwater, although they are regarded as a minor or insignificant component of the whitebait catch (McDowall and Eldon 1980; McDowall 1984b). It is possible that giant kokopu populations are limited by recruitment, a situation that might be exacerbated by the annual harvest.

While all these factors may have the potential to limit giant kokopu, there is insufficient information to determine which, if any, may be doing so. There is little more information on habitat to suggest that it is limiting, except that the decline of the species in many areas has coincided with major land use changes. The investigation of habitat was deemed a worthwhile "first step" towards determining limiting factors, and had the advantage of being readily examined. If habitat availability is limiting giant kokopu, then identifying, conserving and managing their habitat is obviously important.

6.2 Critical features

This report has highlighted five critical features of giant kokopu habitat, namely

- instream cover,
- water velocity,
- overhead shade/riparian cover,
- proximity to the sea,
- water depth.

It must be emphasised that statistical models used to analyse these features are based mainly on information from flowing water (lotic) habitats, as data from most still water (lentic) habitats were less explicit. Nevertheless, some data for lentic habitats are included in the discriminant functions and logistic regression analyses, and I assume that the same habitat features are critical for both lentic and lotic environments in the wide range of water types where giant kokopu occur. That giant kokopu are found in a wide range of water types does not imply that there are no common critical habitat features.

There is also an underlying assumption that the places where giant kokopu were caught or seen represent "normal" habitat for the species, whereas it is possible that they use quite different habitats at different times, or when undisturbed. Unfortunately, I cannot speculate on how well any habitat features model based on Westland and Southland data would perform in other areas of New Zealand.

The habitat requirements of giant kokopu have previously only been described in a generalised manner, as most studies have concentrated on other aspects of the fish's ecology and biology, such as diet, age and growth. As part of a study on fish habitat and the effect of forestry practices, Taylor (1988) reported briefly on giant kokopu and their habitat attributes, from fish captured in South Westland. His results closely resemble what was found during this study, and can be summarised as follows:

- Giant kokopu were coastal, and records declined with distance inland and elevation.
- They were found in a variety of habitats including coastal lakes, swamps, and slow-flowing rivers and streams.
- They were mostly found in slow moving water.
- They were cover dependent and predominantly associated with submerged, emergent and overhanging vegetation as well as submerged logs.
- They were associated with murky, tannin-stained water with low pH and muddy substrates.
- They seldom co-occurred with trout.

West (1989) described the habitat of giant kokopu in some tributaries of the Waikato River as usually being lowland waters with significant riparian vegetation. He suggested that the relative scarcity of large galaxiids might have been associated with poor recruitment from the main river and a lack of suitable adult habitat, both exacerbated by human impacts such as agricultural development and the introduction of exotic fish.

Analysis of the chemical features measured in the field during this study were inconclusive, but overall it appears that giant kokopu are mostly found in acidic (low pH) waters. In Westland, the region where giant kokopu have been most frequently recorded, they are often associated with dark, tannin-stained water. Collier and Winterbourn (1987) reported that brown, naturally acidic waters were abundant in South Westland as a result of geological influences and acid inputs from decomposing forest litter. Main (1988) reported that kokopu whitebait had no pH preference, and there was nothing to suggest that chemical cues *per se* were primary determinants of kokopu distributions. Thus, although they are frequently encountered in acidic waters, pH is not necessarily a feature that influences giant kokopu distribution.

Temperature preferences were not apparent from NZFFD records. Giant kokopu may be encountered more frequently in cooler waters, but this may simply be a function of their geographical distribution; there are many more giant kokopu records from Westland or Southland than from the warmer northern regions. Main (1988) concluded that although large galaxiids (including giant kokopu) were amongst the most thermally intolerant of the native New Zealand fishes, their distributions were not limited by temperature.

Until recently, giant kokopu were generally regarded as poor climbers, and although they are mostly found at low elevation, it has become increasingly obvious that some giant kokopu do travel considerable distances upstream and attain significant elevations. They are apparently also capable of ascending substantial waterfalls, as reported by Hanchet (1990). Landlocked populations of giant kokopu occur both coastally and at considerable elevation and distance from the sea. Overall, however, the description "coastal species" is quite fitting, and the probability of encountering giant kokopu appears to decrease with distance from the sea. It may be that they are coastal only because the type of habitat they prefer is found at low elevations, and not because of an inability to penetrate inland. Giant kokopu may be more likely to occur in streams, rivers and drains if there is a direct connection to a substantial body of fresh or estuarine water, and in Westland and Southland giant kokopu are frequently encountered in relatively small streams and drains connected to the extensive coastal lagoons, swamps and lakes.

The success of artificial habitat structures in a small Westland stream emphasised the species' preference for log and debris as instream cover, and for low water velocities. The construction of such structures in an attempt to enhance giant kokopu habitat would be risky, as there may be serious impacts to the hydrology and ecology of the stream. There may be some circumstances where habitat enhancement is justified, however placing such structures in waterways appears to provide only temporary habitat. Most importantly, there is no implication that they would increase the standing stock of giant kokopu in a catchment. The presence of giant kokopu under culverts and bridges perhaps indicates that giant kokopu utilise these structures as "cover" and further implies that cover may be limiting giant kokopu populations in some streams.

Overall, the intuitive knowledge gained during this research, the analysis of critical habitat features, and all the incidental information in the literature support the view that in all water types giant kokopu are very strongly associated with cover, slow or still water, and proximity to the sea.

6.3 Regional differences

Initially there appeared to be some marked differences between habitat selection in Westland and Southland. Giant kokopu in Westland streams, ponds and lagoons were generally associated with instream cover consisting of logs and debris, and mostly with riparian cover consisting of native bush, scrub, flax or raupo. In Southland they were mostly found in streams and drains with instream vegetation cover and riparian cover mostly of grass. However, native bush and instream logs were certainly not a feature of the pastoral waterways of Southland, and many of the areas sampled in Westland had little instream vegetation.

All this implies that it is the presence of some form of instream and riparian cover that is important, rather than its composition. The features that were identified as critical were so for both regions, and common for the range of water types surveyed. Thus rather than differentiating between regions, this study has highlighted the common features which contribute to the presence of giant kokopu in diverse environments.

6.4 Habitat requirements of juvenile giant kokopu

Juvenile and adult giant kokopu were sometimes caught in close proximity to one another, and there is little to indicate that juveniles occupy different habitats from adults. Observations of landlocked giant kokopu in a pond in Southland indicated that adults were more active at night, while post whitebait juveniles became inactive, choosing to lie in extremely shallow water amid twigs, debris and weeds (Rasmussen 1990). There is very little information of the habits or habitats of diadromous juveniles, and so few juvenile fish have ever been recorded on the

NZFFD that I can not rule out the possibility of their occupying some habitat(s) that are distinctly different from those of adult fish. Discriminant functions analysis showed that water depth and velocity were less critical for juvenile giant kokopu, although there were fewer data and the model was less reliable for juvenile fish. During field work, some small giant kokopu were found in areas of faster-flowing water, perhaps because they could avoid the water flows by occupying small gaps amongst the substrates and instream cover.

Unfortunately, juveniles may be much less likely to be caught using commonly applied sampling methods. Electrofishing is a size-biased technique, and large fish are more likely to be stunned and caught with an electric fishing machine (Lamarque 1990). This bias may be exaggerated in areas of dense instream cover where, even if stunned, small fish may not be seen. Juvenile fish are also unlikely to be caught in fyke nets set by commercial eel fishers, as small fish might either escape through the mesh or be eaten by larger fish (e.g. eels) caught in the net.

6.5 Diet and the importance of cover

Giant kokopu prey upon a wide range of aquatic invertebrates, terrestrial invertebrates, and fish. Their body shape and fin arrangement probably provides them with the capability of sudden "bursts" of acceleration necessary to ambush prey in the water, as noted by Eldon (1969) and Jellyman (1979), and their bilateral accessory lateral line presumably assists them in locating foods near the water surface (McDowall 1997). Thus the description of giant kokopu as a "skulking predator" (McDowall 1990) seems particularly apt, given their diet and preference for dense instream cover in which to hide.

The importance of terrestrial items in the diet of giant kokopu may be linked to their association with overhead shade and riparian vegetation. All three species of kokopu (giant, banded and shortjawed) have significant proportions of terrestrial items in their diet (Main 1988; Rasmussen 1990; Jellyman 1979; West 1990; McDowall et al. 1996b). For giant kokopu this is particularly so in lotic environments. Riparian forest also influences the physical nature of streams by providing stream channels with fallen trees, branches and roots. These provide instream cover, and also alter flow conditions, allow bed materials to accumulate, and give rise to pools (Bisson et al. 1982; Heifitz et al. 1986).

Thus, riparian vegetation may supply a source of food, and slow moving, relatively deep water with instream cover may provide conditions suitable for giant kokopu to ambush their prey. Riparian vegetation and overhead shade may also provide protection from predation, e.g., by birds such as the Harrier (*Circus approximans*) which has been observed capturing migrating ripe male giant kokopu in shallow water (McDowall 1990).

Occupying pools with instream cover may have some energetic advantage, as giant kokopu are presumably not required to spend much time maintaining a high swimming speed in fast flowing water. Such habitat possibly provides a refuge from severe flow changes, as the deep slow-flowing pools would probably suffer less impact during extreme low-flow events and be less susceptible to damage from floods.

6.6 Are giant kokopu rare, endangered or vulnerable?

The region where giant kokopu are now most common (Westland) is also probably the least developed region in New Zealand. However, giant kokopu are also relatively common in Southland, where they are found predominantly in highly modified streams and drains, as well as dredge ponds and coastal lakes, amongst pastoral land that has been developed for many years. Giant kokopu could not be described as rare in either of these two contrasting regions. Whether the species is vulnerable to extinction or endangered is unclear, as in other areas of New Zealand, particularly the eastern coasts of both the North and South Islands, giant kokopu are so infrequently encountered that they are best described as rare or even extremely rare. There are apparently so few giant kokopu in these areas that they may well be highly vulnerable to even moderate changes in their environment, and giant kokopu could be regarded as "locally endangered".

Thus there is a strong geographical contrast in the species' status, and I find it impossible to assign any particular designation that adequately describes giant kokopu abundance or vulnerability on a national basis. If habitat is limiting giant kokopu, even in the regions where giant kokopu are most frequently encountered, then this species is vulnerable to changes in land use or environmental changes that alter the habitat.

Analysis of information from the NZFFD has shown that giant kokopu utilise a very broad range of water types, from small streams and drains, to rivers, ponds, swamps, and lakes. This feature, and their ability to form landlocked populations, may significantly lessen any vulnerability to extinction, though I would stress that survival of giant kokopu limited to landlocked populations should not be regarded as anything better than an extreme measure to be adopted as a last resort. Such a population would not represent the natural biological characteristics of the species, would in all probability contain only a fraction of the species' genetic diversity, and could be highly vulnerable to local extirpation. A conservation goal for giant kokopu must be retention of populations that undertake the sea-migratory life history.

6.7 Impact of whitebait harvesting

Sampling shows that giant kokopu are taken in the whitebait fishery (McDowall and Eldon 1980; McDowall and Kelly 1999), and tend to appear in the whitebait catch during early November, McDowall and Eldon (1980) suggesting about the second week. The most intensive fishing takes place in Westland, which is also where the greatest numbers of giant kokopu are found. Since the whitebait-fishing season in Westland continues until 14 November (under the West Coast Whitebait Fishing Regulations), there is a period of overlap between capture of whitebait and the migration of giant kokopu. It was on the basis of this overlap, combined with concern about the conservation status of giant kokopu, that the Department of Conservation proposed an earlier cessation of whitebait fishing in West Coast rivers in 1994. Data collected since that time (McDowall and Kelly

1999) suggest that migrations of giant kokopu persist through November and into December, which may be interpreted as indicating that capture of giant kokopu whitebait in the fishery need no longer be a matter of serious conservation concern.

Unfortunately, data are still quite sparse, and are based on rather erratic and inconsistent sampling. In particular, it is not yet known what proportion of giant kokopu migration takes place beyond the fishing season (after 14 November). Although the recent data do alleviate concerns, a precautionary approach is desirable. Obtaining further and more reliable data on this question is a substantial and costly task. Ideally, what is required is to undertake a rigorous, quantitative sampling programme on a chosen river system in which day by day variation in the numbers of giant kokopu migrating is determined. Until that is done, all that can be stated with any assurance is that giant kokopu whitebait migrate late in the season, and continue to migrate at least into December.

6.8 Impact of commercial eel fishing

Eels constitute a significant fishery resource in New Zealand (Jellyman 1993), and in recent times there has been intensive commercial exploitation of eel stocks. It is possible that eel fishing has had some impact on giant kokopu populations, although any such impact would be difficult to measure.

Most commercial eel fishing is done with fyke nets, in which giant kokopu also seem to be readily caught. Anectodal evidence from eel fishers, particularly in Southland and Westland, suggests that adult giant kokopu are frequently caught in some locations. In a trial catch and effort diary programme, ten commercial eel fishers operating in the lower South Island (mainly Southland and Otago) caught a total of 334 kokopu in fyke nets during the 1996-97 eel fishing season (M. P.Beentjes, NIWA, pers. comm.). Presumably these were predominately, if not exclusively, giant kokopu, caught during a total of 419 fishing trips representing more than 14000 net/nights of effort.

While giant kokopu may be "hardy" fish, being caught in fyke nets can only have a deleterious impact, as not all fish will survive being trapped in a fyke net, with numerous eels, for a night or more. Careless treatment of any giant kokopu in the nets may also result in significant mortalities.

There is a possibility that removal of eels by commercial fishers is of benefit to giant kokopu stocks. There certainly appear to be viable populations of giant kokopu in areas such as Southland that are heavily and regularly exploited by commercial fishers, some of whom might argue that removing large predators and competitors increases the survival and growth of other species such as giant kokopu.

Regardless of any impacts they may or may not have on native fish populations, some eel fishers do already provide important information on the distribution of giant kokopu, and other species. In fact, some eel fishers may be able to add significantly to our knowledge of the native fish fauna, in particular giant kokopu, as they probably have more interactions with the fish than anyone else. There may be further potential for "picking their brains" about aspects of giant kokopu life history, especially evidence of spawning migrations and habitats.

6.9 Impacts of introduced species

There has been a long and active history of introducing exotic plants and animals into New Zealand (Thomson 1922), and although this has gained wide attention, there has been little explicit study of the relationships between the indigenous and introduced fish fauna (McDowall 1990). Townsend & Crowl (1991) suggested that studies implicating the introduction of trout as a principle cause of galaxiid decline, (eg. McDowall 1968b; Cadwallader 1975a, 1975b; Glova 1989), have not permitted firm conclusions because of design limitations.

Taylor and Main (1987) captured few giant kokopu, banded kokopu or koaro from habitats containing adult brown trout in South Westland, and Allibone (1997) observed a lack of sympatry between kokopu and salmonids in coastal

Otago. Trout and galaxiids have commonly been reported as being spatially segregated in some catchments (Frankenberg 1966; Hopkins 1971b; Tilzey 1976; Cadwallader 1979; Jackson 1981; Townsend & Crowl 1991).

The potential impacts of introductions may include habitat disruption, competition for food or space, and predation. Brown trout is the species thought most likely to be incompatible with giant kokopu (McDowall 1990). Analysis of the NZFFD indicates the two species are not mutually exclusive, but are less frequently found together than might be expected, given that both species are widespread and occur in a broad range of water types throughout the country. There is little to suggest that the presence of brown trout would significantly disrupt the habitat for giant kokopu, and any impacts would most likely be from competition and/or predation, as outlined in Crowl et al. (1992).

The distribution of giant kokopu may be influenced by predation by piscivorous brown trout, as described by Fletcher (1978) for *G.olidus* in Victoria, Australia, and by Townsend & Crowl (1991) for *G. vulgaris* in New Zealand. Competition for space, perhaps combined with competition for food and predation by trout, could explain declines in *G.vulgaris* populations (McIntosh et al. 1992).

Land-use changes, as well as the introduction of exotic species, may also have significant impacts on the native fish, as concluded by Minns (1990). It would be difficult to quantify these impacts or to distinguish between the causes, and Chadderton and Allibone (1996) concluded that a combination of the absence of both introduced fish and habitat destruction explained the higher abundance of large galaxiids and their use of mainstem habitats in some Stewart Island streams.

In conclusion, although there is circumstantial evidence that brown trout have caused a decline in giant kokopu populations, the underlying mechanisms have yet to be investigated.

6.10 Seasonal patterns and spawning

Virtually all the field work for this study was done in the autumns of 1998 and 1999, and there is no way of knowing if the habitat criteria described for the autumn are consistent for all seasons. It is quite possible that giant kokopu utilise quite different habitat for breeding, although the success of landlocked populations suggests that neither distinct and separate spawning habitat, nor a marine life-stage, are obligatory. In diadromous populations the availability of spawning habitat (whatever that may be) is possibly a limiting factor.

McDowall (1990) reported downstream migrations of significant numbers of ripe adult male giant kokopu during the late autumn and early winter, possibly coinciding with spring tides, and Jellyman (1979) found ripe males and females in April. The information presented by Rasmussen (1990) is unclear with respect to giant kokopu spawning time, as he reported that in various locations spawning had been mostly completed by late June and July, whereas ripe fish were also observed in August and September. He also reported that eggs were coated with a sticky gel, and that they sank quickly when placed in water and adhered to any material they touched in the water.

Having "sticky" eggs and making downstream migrations near spring tides suggests that diadromous stocks of giant kokopu may have similar spawning habits to inanga (*G. maculatus*), which deposits sticky eggs amongst submerged marginal vegetation near peak spring high tides (McDowall 1990). The spawning of landlocked giant kokopu in ponds and lakes obviously would not be dependent on tidal cycles. Rasmussen (1990) postulated that landlocked giant kokopu did not spawn in response to changes in water level or flooding in ponds, and did not suggest any alternative.

Obviously, there is considerable need for knowledge of the spawning habits and habitats of giant kokopu if rational decisions on its management and conservation are to be made.

6.11 Conclusions on the conservation and management of giant kokopu.

A frequently expressed strategy for conserving and managing fish stocks could be summarised as: "Take care of the habitat and the fish will take care of themselves". There is an underlying assumption that populations of giant kokopu are limited by habitat, mainly because the decline in stocks has apparently matched a decline in available habitat. Much of the decline in the abundance of New Zealand freshwater fish can be attributed to human impact, mostly by changes to the habitat. Since the time of human occupation impacts have included: extensive deforestation, impoundment of rivers, pollution, eutrophication, wetland drainage, water abstraction and the introduction of a host of plants, pests and animals that modify the habitat. If we wish to retain stocks of our indigenous fish, it is obvious that we need to identify and conserve their habitat, and even restore it where practical.

The management and conservation of giant kokopu habitat should be based on the critical features identified in this study: instream cover, low water velocity, water depth and overhead shade/riparian vegetation. Presumably the task of locating giant kokopu and their habitat will continue to be based on field survey work, and involve two separate processes: an assessment of the habitat to see if it meets the identified criteria, and sampling to establish if giant kokopu already occupy it. Both processes are enhanced by knowledge of the habitat requirements of the species.

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